Exploratorium Cookbook II

A Construction Manual for Exploratorium Exhibits
Revised Edition

by Ron Hipschman and the Exploratorium staff

Cover- *Photograph by Susan Schwartzenberg*

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Any opinions, findings, and conclusions, or recommendations expressed in this publication are those of the author and the Exploratorium, and do not necessarily reflect the views of the granting organizations mentioned above.

CAUTION! The exhibits in this publication were designed with public safety and success in mind. But even the simplest device or the most common materials can be harmful when mishandled or misused.

Introduction

This volume contains the second set of exhibit plans published by the Exploratorium. The first 82 plans can be found in the *Exploratorium Cookbook I.* The present volume includes another group of exhibits, some of which have been built in the intervening years, which we feel are significant and replicable additions to our museum.

Some slight changes have been made to the format of the *Cookbook,* such as the addition of exhibit graphics in each recipe, and a drawing of each exhibit with a person using it, to denote its scale.

None of these exhibits should be considered absolutely fixed in its design or construction, and readers should feel free to modify the exhibits to suit their own environments, materials on hand, or aesthetics. Of course, the exhibits as they are presented in the *Cookbook* are extensively tested on the floor of the Exploratorium, and any modification made to our design could affect its durability or effectiveness.

Each recipe is divided into three sections. The **Description** section briefly tells what the exhibit is supposed to show, and how it is worked. The **Construction** section contains the details on how to build the exhibit as it is found in the Exploratorium. The last section, **Critique and Speculation,** gives some of the problems—both mechanical and pedagogical—which we have encountered. This section also suggests some possible improvements to the exhibit. These improvements are included in this section rather than in the Construction section because they have not been tested, and we have found that even the most trivial modifications can profoundly affect the exhibit's performance. We keep a watchful eye on new exhibits by placing them just outside our shop for a minimum of one month before they are taken to their respective sections of the museum.

In each recipe we have attempted to supply all of the essential information about the exhibit. If measurements or other specifications are absent, it can be assumed that they are not critical within obvious limits. We expect that you will adapt such non-critical features to your own requirements.

The **Exhibit Design Checklist** which appeared in *Cookbook I* is repeated in this *Cookbook.* This is a list of some of the things that are important to remember during exhibit construction. Most of the items are on the list because we have overlooked them in one or more of our exhibits in the past. Scanning this list could save you time, money, and possibly some frustration.

On a final note, many of you may not be aware that the Exploratorium builds exhibits for other museums and institutions. Our Exhibit Services Group offers a wide range of support including museum design, thematic planning, exhibit design and production, and program development. The exhibits produced by Exhibit Services take a big step beyond the prototype by utilizing the finest in materials, thereby achieving a high degree of durability and handsome appearance. If you are interested in knowing more about the Exhibit Services Group, please contact them through the Exploratorium.

Acknowledgments

It is extremely difficult to write an acknowledgments page for a publication which has involved as many people as this one has. My part has been only a small piece of the total work that has gone into this *Cookbook*, and the writing may indeed have been the easiest part of the project.

First and foremost, the exhibit designers and builders (both past and present) at the Exploratorium need to be thanked for their help in providing construction details of the exhibits. This was a sometimes difficult task when methods and materials were lost somewhere in time or space. Many hours were spent researching old plans and files, suggesting possible improvements, and finding new suppliers for certain materials and parts. The National Science Foundation provided the funds to build many of the exhibits that are included in this *Cookbook*.

Major credit must go to the people involved in the actual production of the book: Susan Schwartzenberg for her laborious (and beautiful) layout job, David Barker and Peter Still for their many additional detail drawings, and to Bob Miller, Michael Pearce, Frank Oppenheimer, and Rob Semper for their editing and proofreading suggestions.

Ron Hipschmann

Credits

Production: Susan Schwartzenberg
Detail Illustrations: David Barker, Jad King, and Peter Still
Exhibit Illustrations: Jad King
Cover Photograph: Susan Schwartzenberg

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Exhibit Design Checklist

Overall Exhibit Design

( ) The design of the exhibit should suggest how it is to be used.
( ) Power switches are operated by clearly marked mat switches or timed push buttons.
( ) Adequate space and mounting surfaces are provided for explanatory graphics.
( ) Exhibit components and graphics are adequately lit, using backlit graphics for dark display areas.
( ) Children can use exhibit readily.
( ) Exhibit is accessible to people with wheelchairs or walking aids.
( ) Lettering is large enough for people with impaired vision.
( ) Speakers are tilted toward the visitor to localize sound from the exhibit.
( ) Exhibit is carefully located and oriented on the floor.
( ) Power and other utilities are available where the exhibit is located.

Mechanical Design

( ) Exhibit has a stable base and a low center of gravity.
( ) One person should be able to move the exhibit, using a forklift if necessary.
( ) All internal parts, circuits, labels, etc. are securely fastened.
( ) To resist breakage, windows and mirrors are made of plastic or laminated safety glass where possible.
( ) Exhibit is built with quality components. (This is usually cheaper in the long run.)
( ) Exhibit uses standard components and hardware to reduce the spares inventory and repair time.
( ) Consider using hand cranks in place of reversing electric motors.
( ) Knobs on pots have small radii or slip clutches to limit the force with which they can be turned.
( ) Small loose parts, such as viewers, can be attached with wire rope or braided cord leashes. (You can make a leash that retracts using a counterweight attached to one end of the leash. The weight slides in a vertical tube; a bushing keeps the weight from pulling out of the tube.)

Accessibility

( ) Wherever possible, subsystems can be removed for service.
( ) Adequate work space is provided in exhibit enclosures. (Hinged panels with wire harnesses work well.)
( ) Frequently replaced items, such as lamps and tapes, are stored at the exhibit, accessible through a hinged door or sliding panel with a lock.
( ) All service panels are secured with the minimum necessary hardware. (Flush-mounted locks are best.)

Electrical Design

( ) Power cords are grounded and fused.
( ) Exhibit power switch is easily accessible to the staff but not to the public.
( ) Power switches switch both sides of the line.
( ) All lethal voltages have special safety interlocks on access panels, with crowbar relays to discharge capacitors.
( ) High voltage semiconductors have insulating caps.
( ) All high voltages are conspicuously labeled.
( ) Variations in line voltage are provided for.
( ) A power outlet is built into the exhibit for maintenance tools and lighting.
( ) Components prone to failure, such as tape decks and foot switches, have quick connectors.
( ) Power cords have complete strain relief.
( ) All wiring is shielded from sharp edges and abrasion.
( ) Movable components, such as lamps and headsets, have special strain relief. (Test probe wire can be used in low current applications.)
( ) All common adjustments are easily accessible and clearly labeled.
( ) All distinct subsystems can be isolated for testing or replacement.

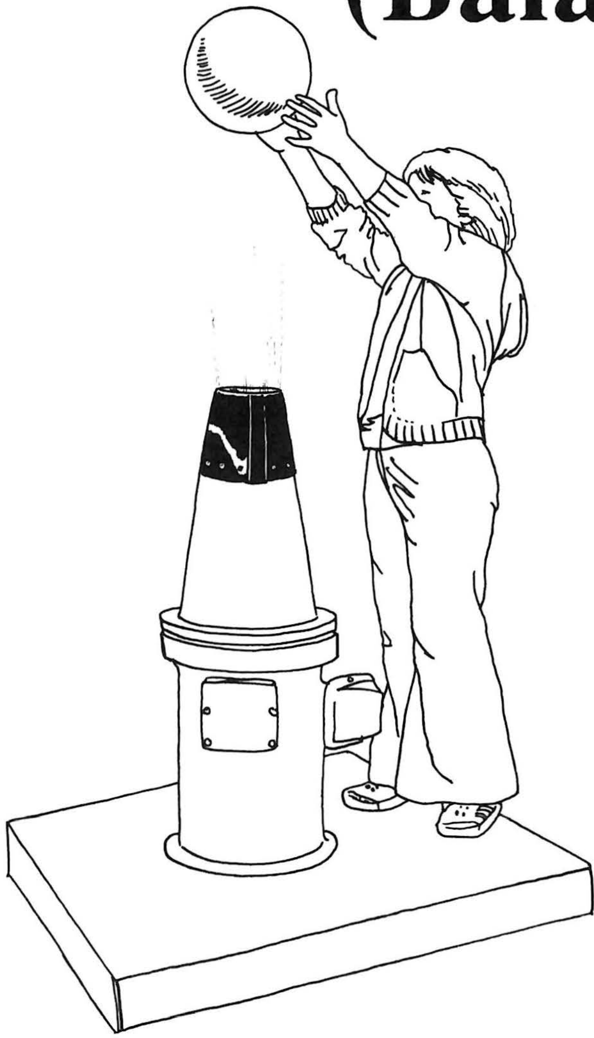
Ventilation

( ) Hot lamps and other components are vented and shielded from children's hands.
( ) Air space is provided around all electrical packages.
( ) Convective openings are above and below all heat sources, such as lamps, motors, and power supplies.
( ) If forced air cooling is used, it is filtered.
( ) Semiconductors and high wattage resistors have heat sinks adequate for all weather conditions.

Longevity

( ) Complete checklist is drawn up for routine maintenance, with recommended intervals for checking levels, cleaning vents, lubrication and so on. Checklist should include an easy way to keep maintenance records.
( ) Troubleshooting guide is prepared for exhibits where symptoms of failure are predictable.
( ) Surfaces are all non-porous to resist wear and dirt. In the long run, plastic is usually cheaper than paint. We recommend avoiding using plexiglass for horizontal surfaces, because it often gets badly scratched.

Bernoulli Blower (Balancing Ball)



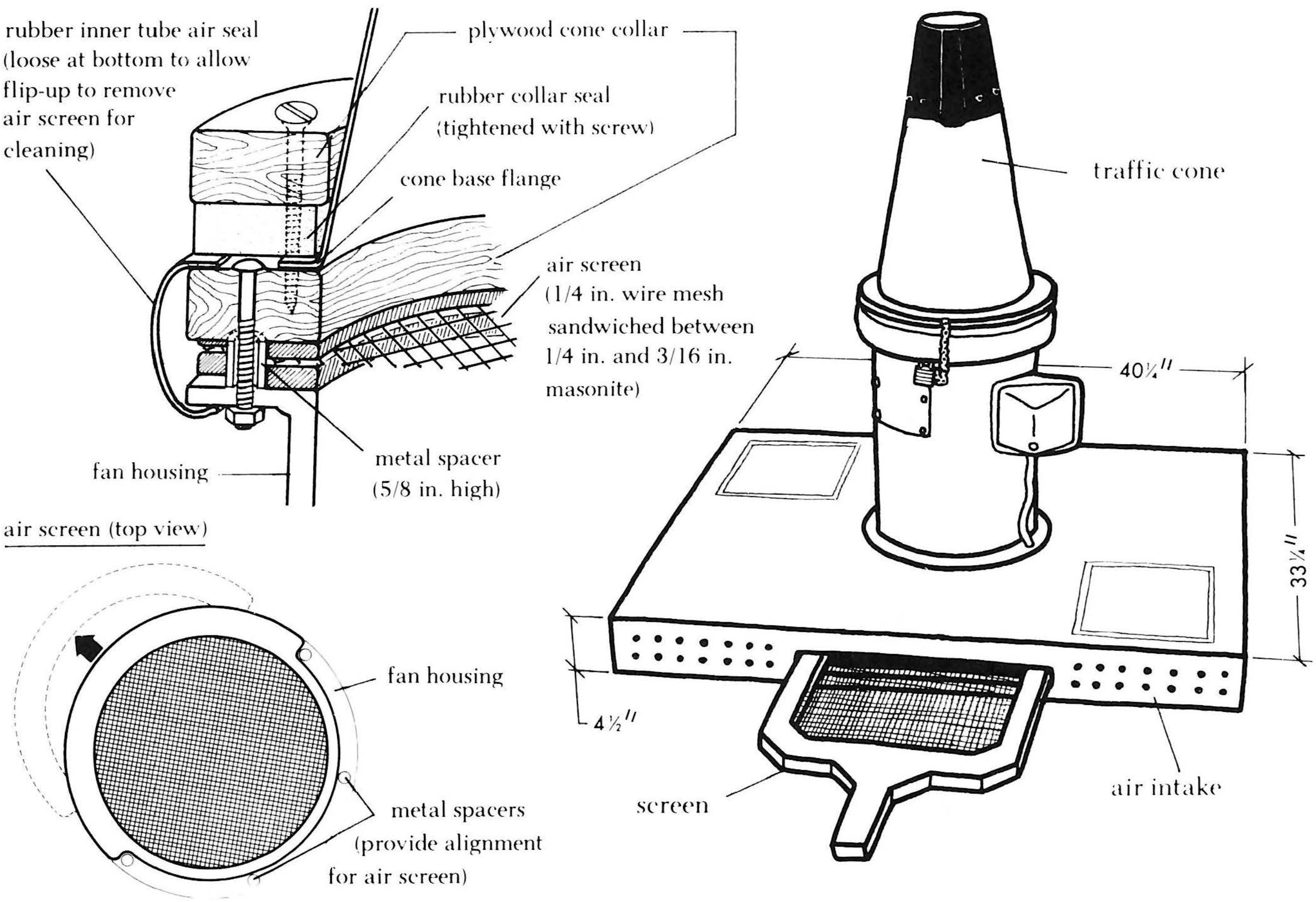
Description

A ball floats, bobbing up and down, 3" above a large plastic cone. Upon closer inspection it is found to be floating on a stream of air blowing out of the cone, generated by a large fan beneath it. If the ball is pulled slowly out of the stream of air, a force is felt trying to pull the ball back into the air stream. If the cone is bent to the side, the ball can be suspended in space off to the side of the blower and cone.

Construction

Our version of this exhibit is built with a very compact vane-axial fan (military surplus) 15" high and 12" in diameter. Power requirements for this fan are 230VDC 1.8A (1/3 HP). A highway cone 24"tall is fastened with a collar over its base to the top of the fan housing and cut off at the top so that the diameter of the orifice is 4". The blower's intake is on the bottom and it therefore sits on a hollow square base 33" square and 4" high. The sides of the

cone collar and collar air screen detail (cross section)



base have been repeatedly drilled through to allow air to get to the fan. A screen accessible from the edge of the base prevents large objects from being sucked up into the fan and expelled at high velocities at people above.

Additions and Changes (1990)

We now extend the tip of the cone with flexible rubber. This prolongs the life of the cone, since the rubber doesn't crack with repeated squeezing. Nowadays, we use a beach ball that is about 12" in diameter.

Related Exploratorium Exhibits

FLUID MECHANICS

Bernoulli Levitator

Exploratorium Exhibit Graphics

To do and notice:

Hold the ball with both hands and pull it slowly out of the air stream.

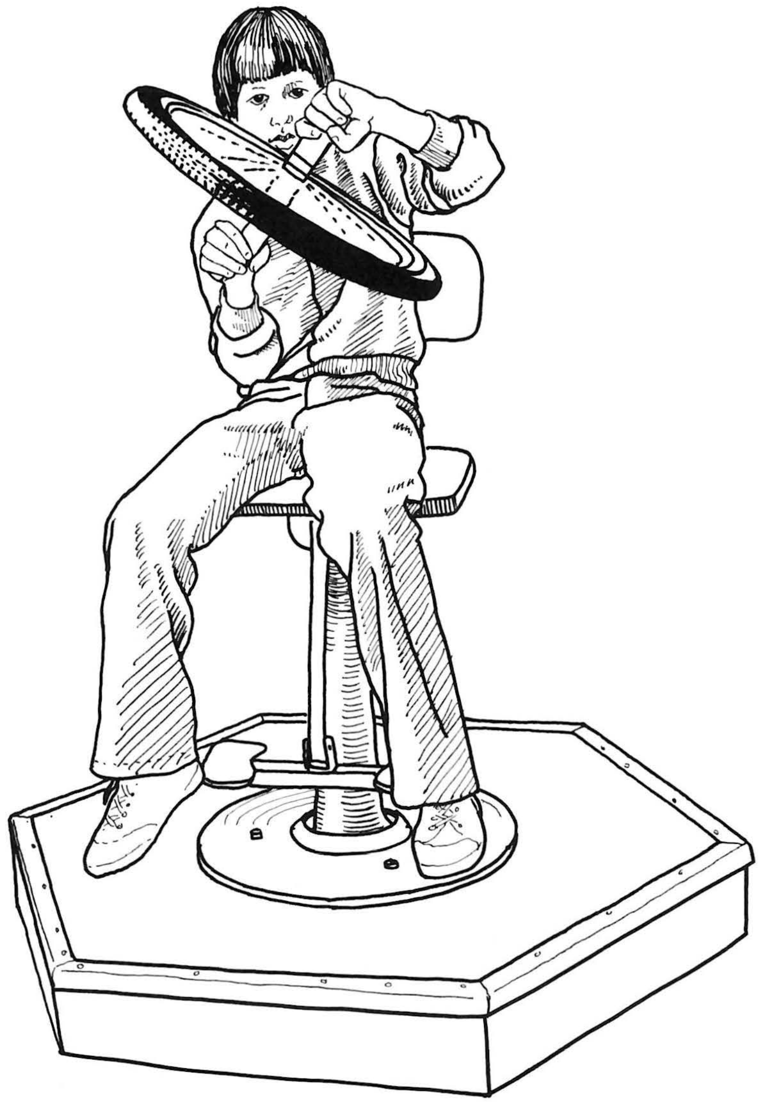
Notice that when only half the ball is out of the air stream you can feel it being sucked back in. If you then let go of it, it will oscillate back and forth without falling to the ground.

What is going on:

When the ball is pulled partially out of the air stream, the air that is moving fast along the side of the ball exerts less sideways pressure on the ball than the still air in the room.

An airplane wing is shaped so that the air moves faster over the top of the wing than it does over the bottom of the wing. The lower pressure on the top of the wing produces a suction which holds the airplane up, or, more accurately, the high pressure on the bottom of the wing pushes the airplane up and balances the downward effect of gravity.

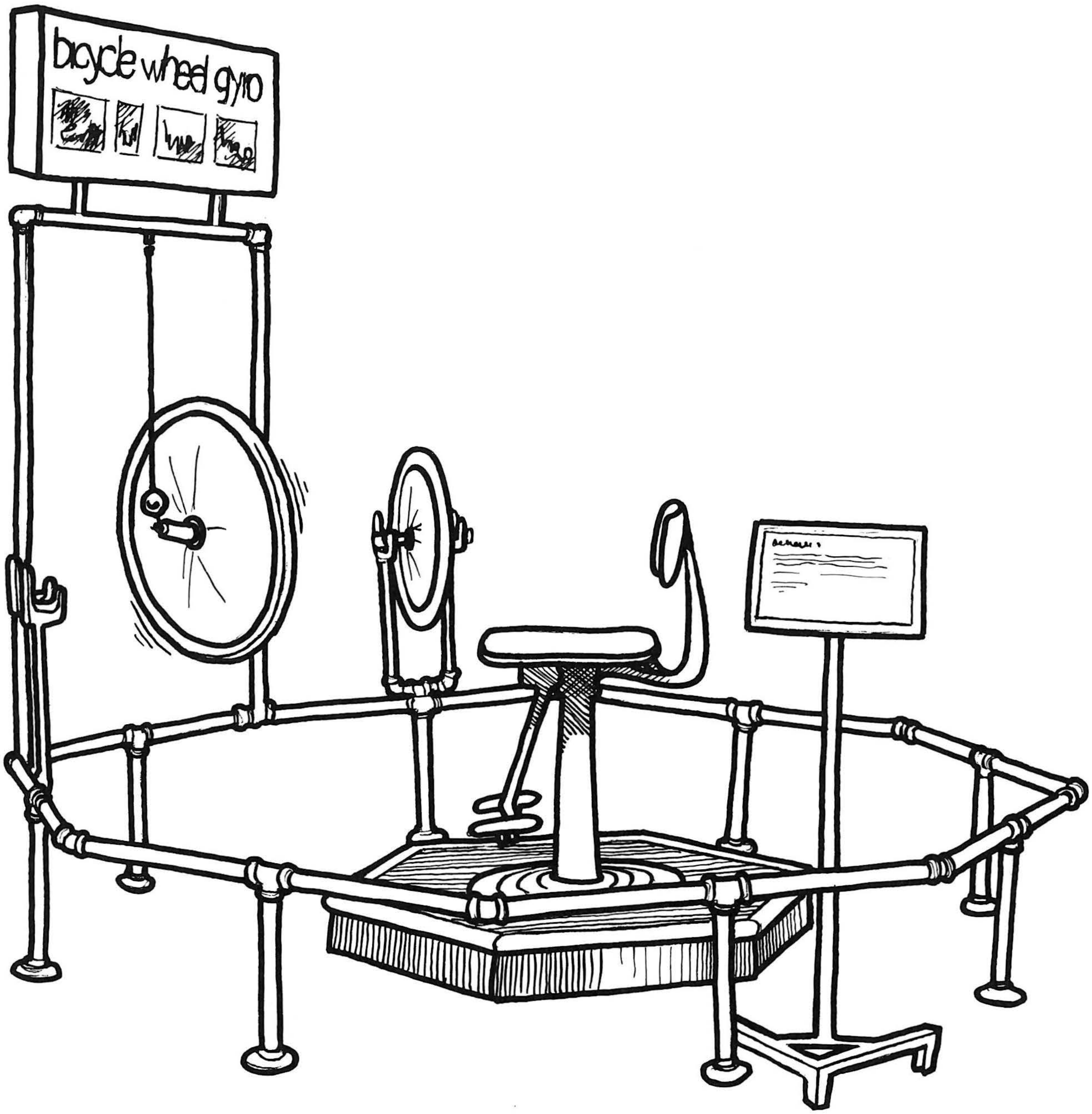
Bicycle Wheel Gyro



Description

The strange, non-intuitive force felt when using gyroscopes can be experienced on a large scale with this exhibit. The visitor sits in a chair which rotates very freely on good bearings and holds a rapidly spinning bicycle wheel with handles at the hubs. As the wheel is tipped to the right or left,the chair spins right or left depending on the direction the wheel is spinning. A wheel can also be hung from a freely rotating cable by an eyeloop in one of its handles. Instead of flopping down (which it does if not spinning) it remains upright and "revolves" around the suspension cable.

The chair sits in the center of a guard rail to keep spectators from being kicked or scraped by the person with the wheel. Attached to the rail are brackets to hold and spin the wheels as well as a place for the hanging wheel experiment to take place.

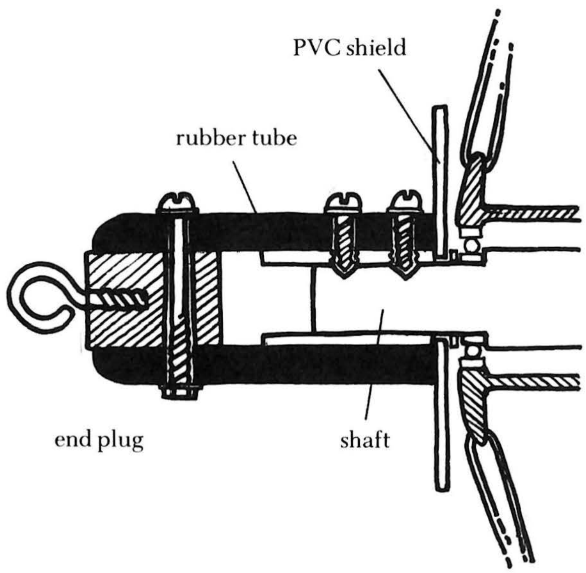


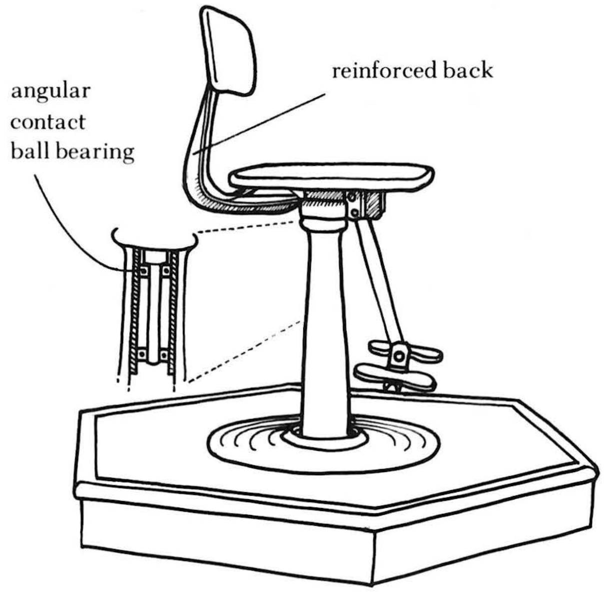
Construction

The rotating chair sits in the middle of an octagonal barrier 36" on a side, made of 1" pipe. The barrier is put together with standard plumbing fixtures (T's, 45 degree joints, right angle joints, etc...). The barrier stands 16" above the ground and thus provides a sufficient barrier to both children and adults. It should be painted a bright color (ours is purple) to keep people from tripping over it. The hanging wheel experiment is done in a large open frame attached to the barrier. The 24" steel cable has a heavy duty swivel at the top and a steel hook and rubber ball (for the user's protection) at the bottom.

Two wheels are provided, one 27"

detail of wheel grip





diam. and the other 19" diam. It is important to supply a smaller wheel for children who have shorter arms than adults and might otherwise end up with skid marks on their noses! We use standard bicycle wheel rims and worn tires with heavy duty spokes and special hubs supplied by Phil Wood. These hubs are used because Phil will supply them without shafts - allowing us to make up a long solid shaft to accomodate the handles - and the hubs take standard ball bearings (hubs with cone type bearings won't last). These hubs are available from:

Phil Wood
638 University Ave.
Los Gatos, California
tel: (408) 298-1540

Companies such as Central Scientific Company (CENCO) might also be able to supply a similar wheel but we chose to machine our own shaft/handle assembly.

The bearings are inserted into the hub with high strength Loctite. The shaft was machined to fit in our shop and has the handles attached to it (see diagram). The spokes of the wheels are covered with sheets of .010" mylar, and silicone sealed to the wheel rim and down the seam of the mylar. Before application of the silicone seal all surfaces must be primed with the appropriate primer available from plastics dealers.

The seat is mounted on a steel shaft which passes through an angular contact ball bearing at the top (which takes care of thrust and radial loads) and a normal bearing a few inches below it. The chair sits on a wide and heavy base. Foot rests have been added to the chair to keep people in as upright a position as possible to minimize their angular momentum while still accommodating all sizes and shapes. The foot rests also keep people from dragging their feet.

Critique and Speculation

This exhibit works very well except that the mylar on the wheels sometimes needs replacing.

Additions and Changes (1990)

After we wrote this recipe, we removed the guard rail on this exhibit because our insurance company felt it presented a tripping hazard. We used 1" pipe to build a stand that could hold the brackets for spinning the wheel and the frame for the hanging wheel experiment. This stand includes a base made of a large steel plate, which prevents the stand from toppling.

Related Exploratorium Exhibits

CONSERVATION OF ANGULAR MOMENTUM

Gyro Chair
Gyro Compass
Gyroscope

Exploratorium Exhibit Graphics

The exhibit graphics consist of a short text which says;
SPIN WHEEL FAST HOLD TIGHT SIT AND TILT WHEEL or HANG IT AND STAND BACK
The text is accompanied by 7 photographs demonstrating the different uses of the exhibit.

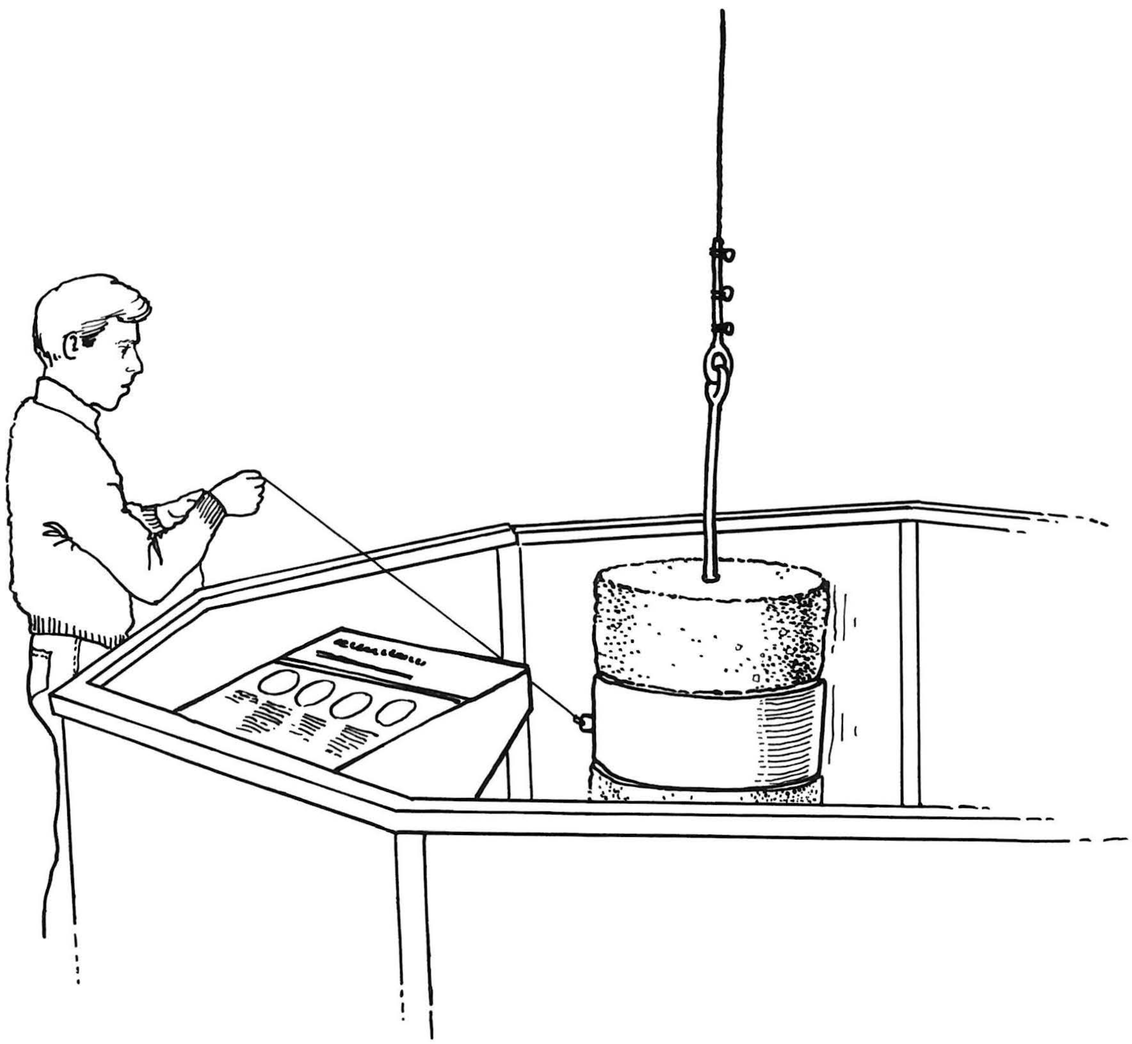
for example;



Photos Larry White

Recipe No. 85

Resonant Pendulum



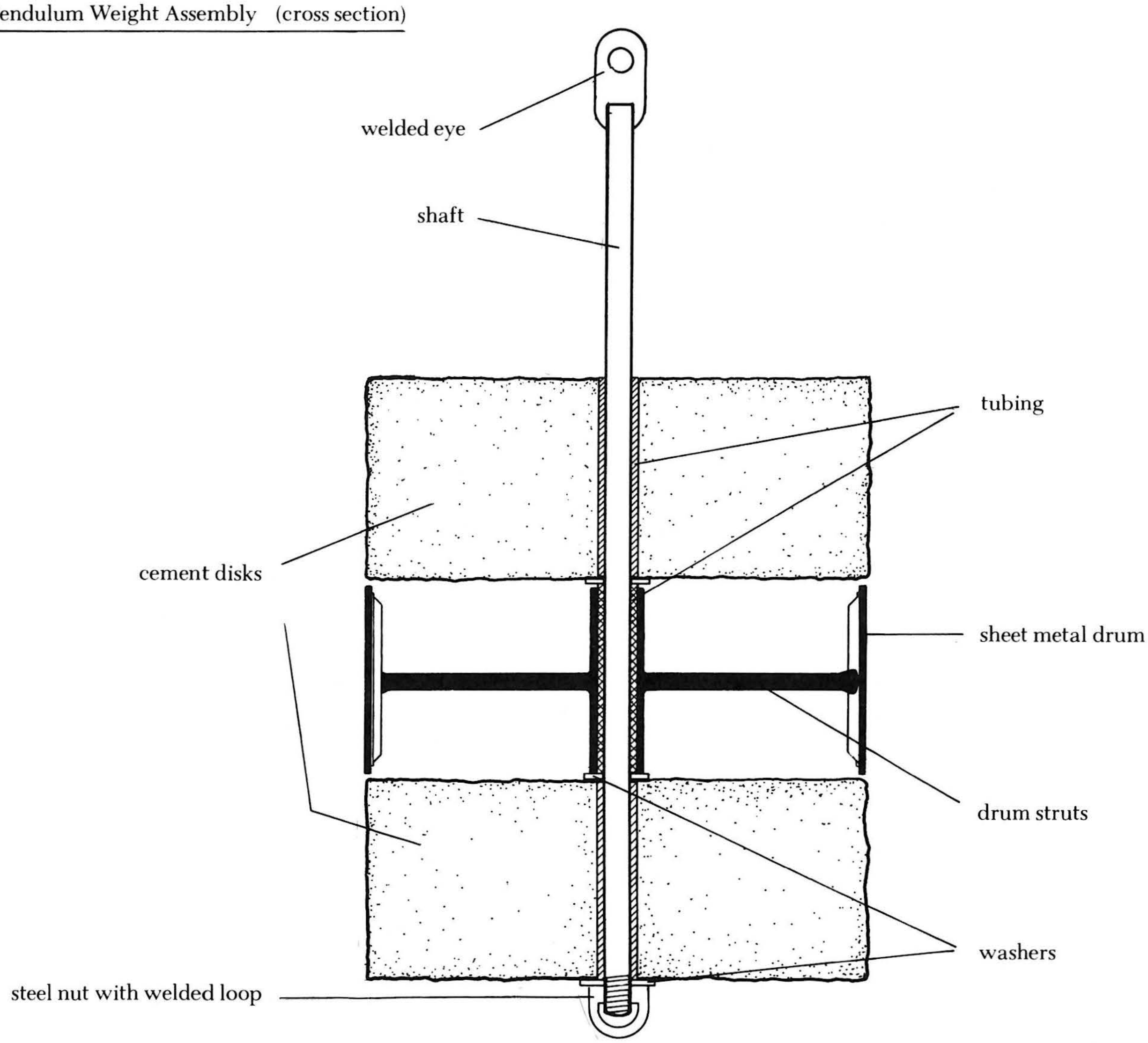
Description

The visitor swings a small magnet onto a steel collar attached to a heavy pendulum hung from the ceiling. Because of the weak magnet, the visitor learns that only by pulling in time with the swing of the pendulum (in resonance), can the pendulum be moved. Two magnets are tied to the fence at 90 degrees to each other so the users, if they cooperate, can alter the pattern in which the pendulum swings (circle, ellipse, line, etc.).

Construction

Two cement weights are cast, measuring 20" in diameter 8" thick and weighing 200 pounds each. The weights are strengthened by steel bars cast into the cement. A steel tube with a 1" hole is cast into the center of each disk along its central axis. This tube allows the two disks to be mounted on a 1" steel shaft, separated by 8". In the space between the disks is mounted a steel sheet metal drum, free to rotate (see diagram). The top of the shaft has

Pendulum Weight Assembly (cross section)



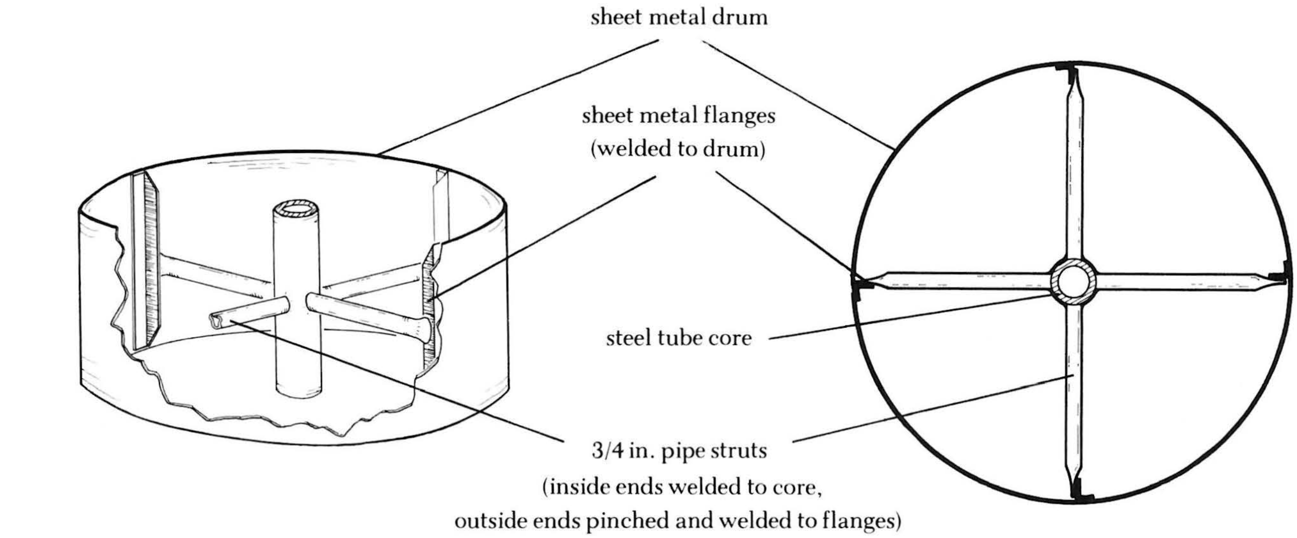
an eye welded to it providing a place to hang the pendulum. The pendulum hangs from a 5/16" steel cable (with counter wound threads to prevent unwinding) from about 35 feet above the floor. The top few feet of the suspension system employ a piece of heavy chain for flexibility when hung over one of our girders. The steel cable, if hung over the girder, would not be as flexible and could fatigue due to the constant back and forth motion of the pendulum. The pendulum is tied to the floor with a short length of nylon cord to limit its swing.

The pendulum is surrounded by a fence (design of the fence is not critical) 10 feet in diameter from which the magnets (ceramic with steel pole pieces) hang on nylon cord.

Critique and Speculation

The "freely" rotating steel collar is not free enough for the weak pull of the magnets and they slide over the surface of the metal instead. This isn't necessarily bad, but not as originally intended. The magnets are subject to quite a bit of abuse and must be replaced frequently.

Detail: Rotating steel drum



Additions and Changes (1990)

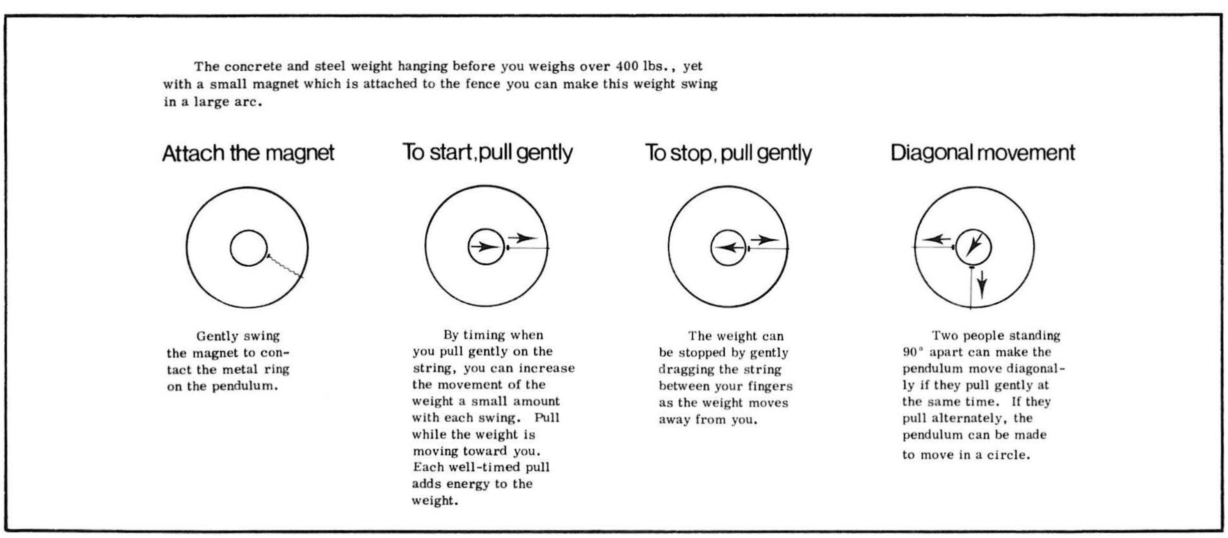
We have increased the life of the magnets by carpeting the floor inside the fence.

Related Exploratorium Exhibits

RESONANCE

Aeolian Harp
Bells
High and Low Q
Kettledrum
Organ Pipe
Resonant Rings
Resonator
Wave Machine

Exploratorium Exhibit Graphics



What is going on:

Any object which returns to its original position or state after being disturbed will vibrate or oscillate about that original position with at least one natural frequency and often several natural frequencies.

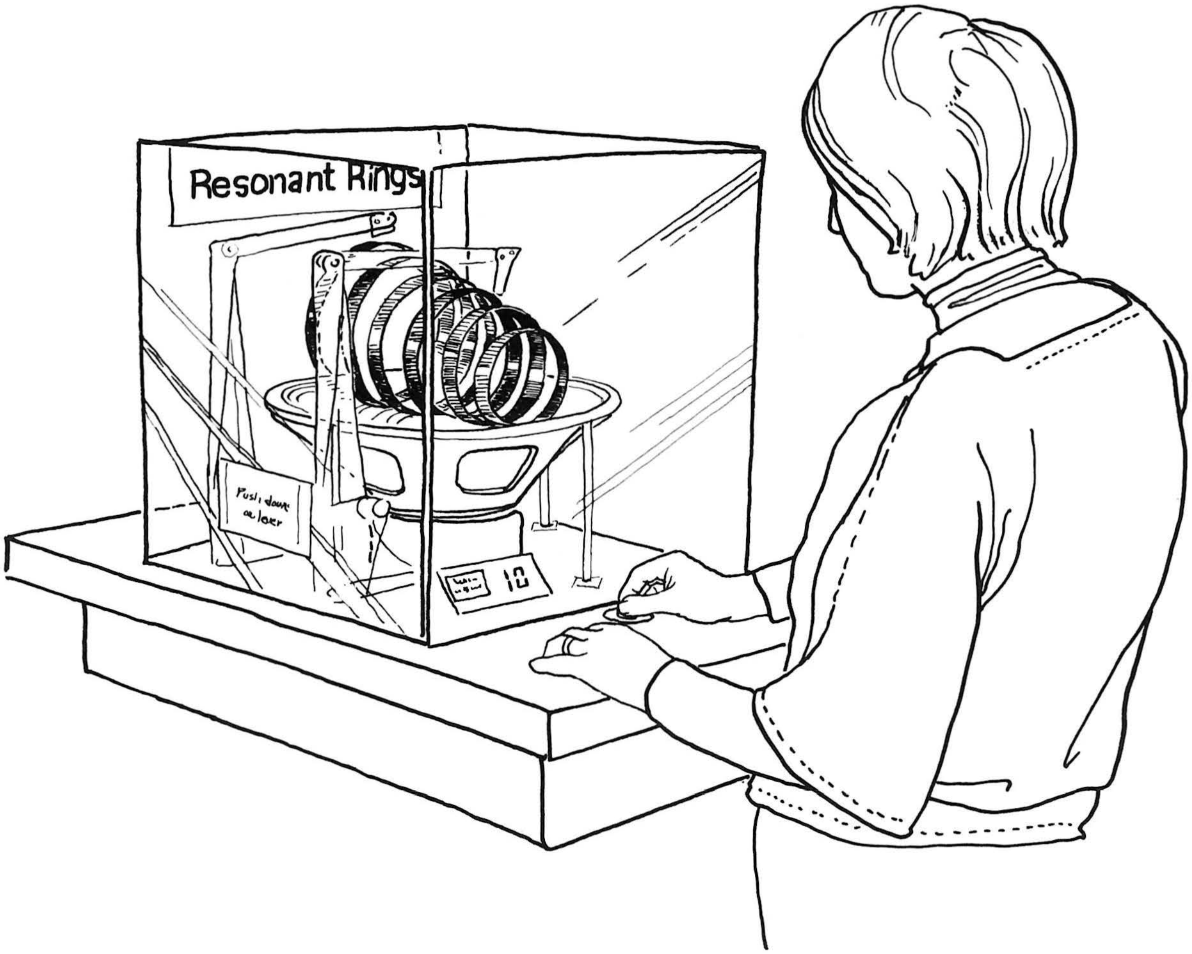
If the object is pushed periodically with a frequency which is not the same as one of these natural frequencies, the object will not respond very much. Under these conditions the push is not always in step with the natural frequencies, and it will sometimes tend to speed the object up and at other times tend to slow it down.

However if the frequency of the push is the same as the natural frequency, the two will remain in step, and each successive step, no matter how small, will increase the motion of the object. The motion of the object is then said to resonate with the motion of the push. Under these conditions of resonance a small effect can produce an oscillation or vibration of enormous size.

If you have an unbalanced wheel or a small bump on your tire, your car will not shimmy badly except at certain speeds when the springs of your car are resonant to the frequency of the rotating tire.

Recipe No. 86

Resonant Rings



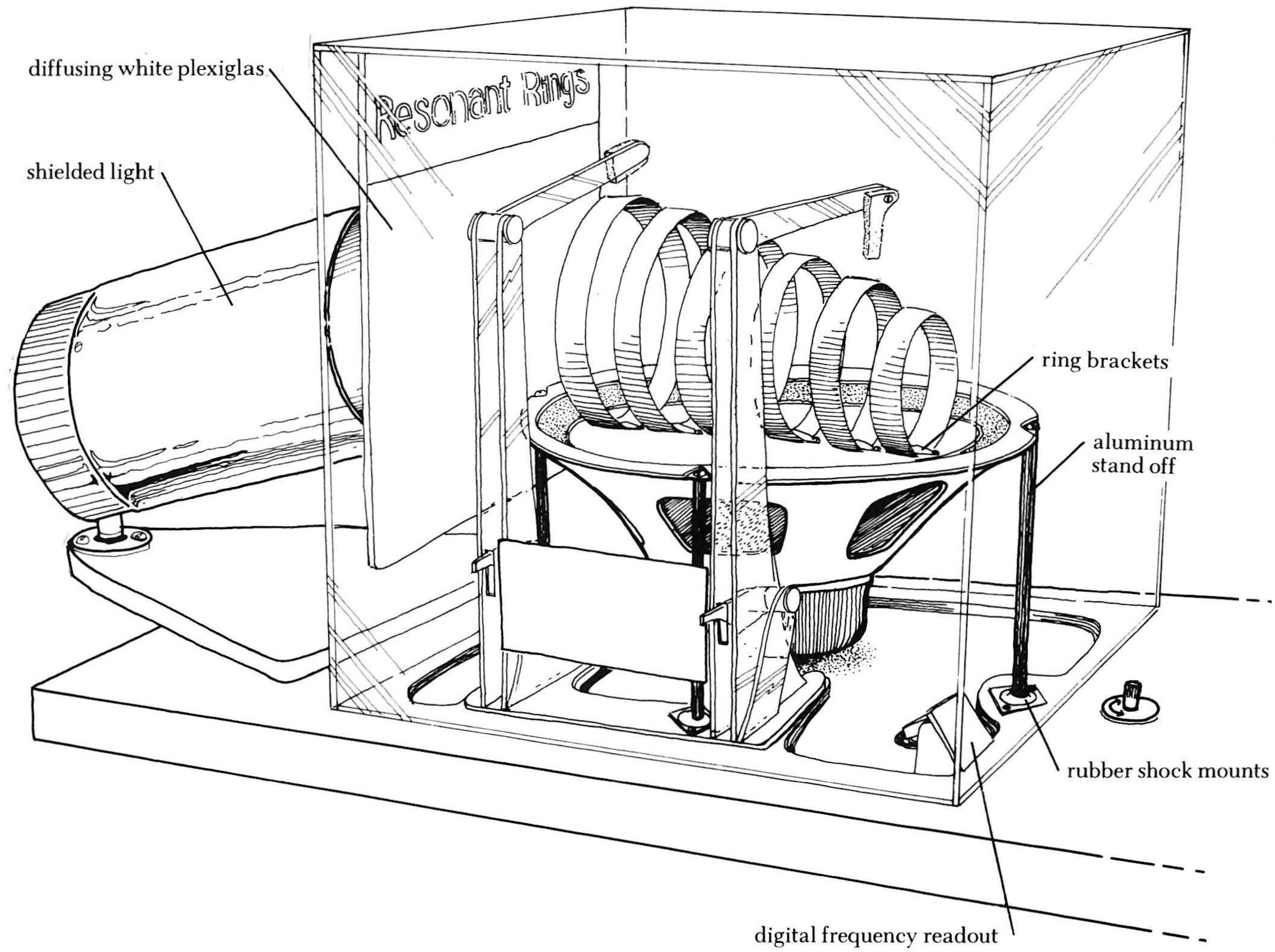
Description

Circular steel bands of various diameters are mounted on a plate which has been cemented to a loudspeaker. By adjusting the frequency of the sound from an oscillator to the speaker, a graphic illustration of harmonic resonance can be seen in the rings as they vibrate at various frequencies and in different modes of vibration. The frequency of the speaker can be read directly on a digital counter. Exciter levers are provided for two of the rings so they may be struck lightly and their "natural frequency" observed.

Construction

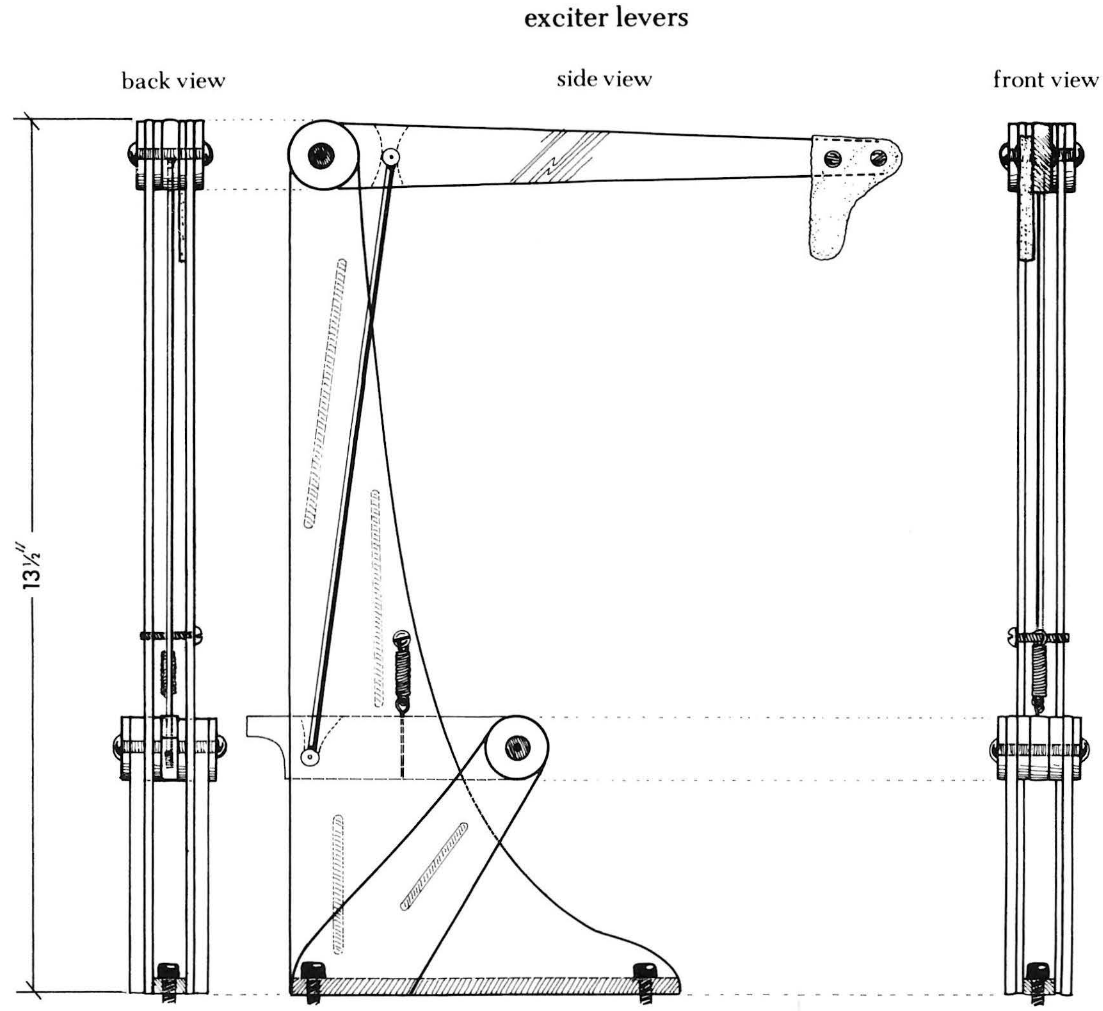
The exhibit is protected by a 1/4" plexiglass box bolted to the table top. The entire tabletop (box and all) is hinged to lift upward to provide access to the electronics which are mounted in the base of the table.

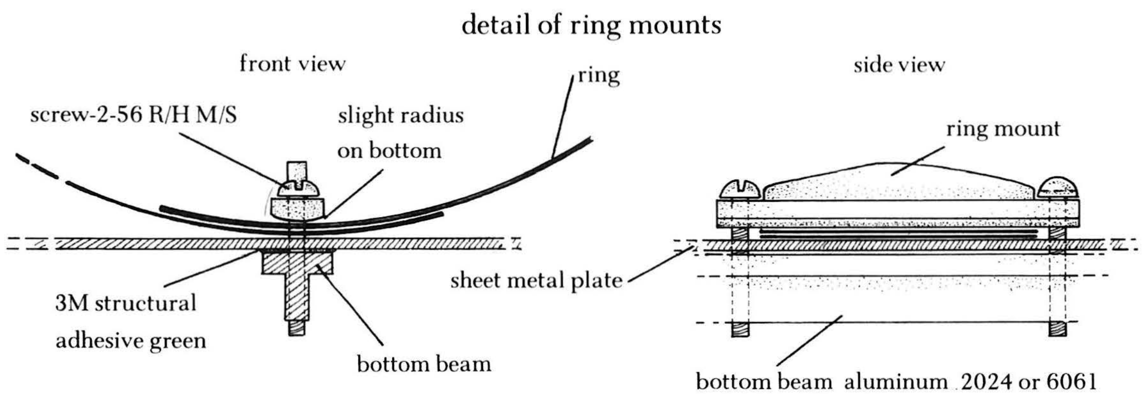
The rings are made of .006" spring



steel 1" in width. The six rings in our exhibit have the following diameters: 4.25, 5, 5.5, 6, 6.5, and 7 inches. The rings are held down on an aluminum disk by machined aluminum brackets. These brackets are screwed through the plate into a drilled and tapped "T" beam previously glued with 3M structural adhesive epoxy to the bottom of the plate. The rings are taped together at the overlap with a piece of adhesive transfer tape and then placed under the brackets and fastened down (see diagram). The plate assembly was then sealed to the cone of a 15" 50 watt (Radio Shack) speaker. The speaker is held above the table in plain view by four aluminum standoffs attached to the table with rubber shock mounts.

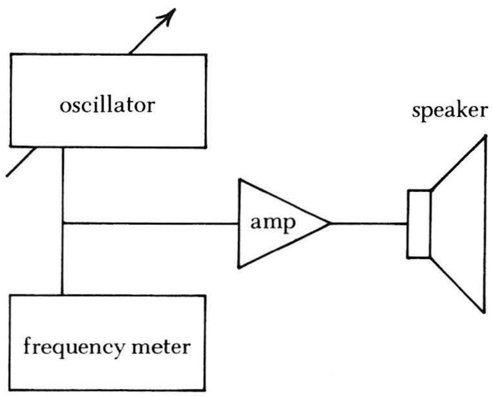
The two exciter levers are mounted next to the speaker and rings with the user controls protruding through the plexiglass box. The levers are only allowed restricted motion to prevent damage to the rings. These assemblies are made out of plexiglass for aesthetic reasons and if this is done the moving parts must have bushings to keep them from wearing out. The only critical measurement for these is that the hard felt tip on each must touch the the ring at its apex.





A flood lamp with a stove pipe shield is mounted in back of the box to provide an illuminated background against which the rings can be easily viewed. To make the illumination uniform, a piece of white translucent plexiglass was affixed to the rear of the box.

Only a block diagram of the electronics is provided since any number of components that would be suitable can be found. One note, however, is that the



adjustable oscillator (ours goes from 7 to 133 Hz.) should have a multiturn potentiometer for fine frequency tuning. For further information about the circuit boards contact the Exploratorium electronics shop.

Critique and Speculation

It is an interesting and advanced exercise to calculate the fundamental resonant frequencies of these loops.

Related Exploratorium Exhibits

RESONANCE

Kettledrum
Resonant Pendulum
Resonator

Exploratorium Exhibit Graphics

The blue spring steel circles are mounted on a loud speaker. The speaker is activated electronically and moves the rings up and down. The red numbers tell how many times the speaker moves up and down per second.

To do and notice:

Turn the control to the lowest frequency and then gradually increase the frequency.

Notice that the largest ring will vibrate strongly at about 7 per second, the next ring at about 8 per second, the third one at 10 per second, and the smallest ring at about 21 per second.

As you raise the frequency each ring will respond again.

Notice that this second response for the large rings is about 25 per second. This vibration is a harmonic (overtone) of the vibration at 7 per sec. Notice that the vibration at 25 has produced five bulges in the ring and five places (including the clamp at the bottom of the ring) where the ring hardly moves at all. The vibration at 7 per sec. has only three bulges and three quiet places.

Look for higher frequency harmonics for the largest ring.

Push a ring down with the lever and release it. The ring will vibrate at its "natural frequencies." The shape does not appear as regular as the resonances because it is a combination of harmonics.

Notice that the rings can respond in more than one way to the motion of the speaker. They can vibrate back and forth or even with a twisting motion with one side of the ring moving toward you and the other side moving away.

What is going on:

The vibration of the loud speaker causes waves to travel around the steel circles. One wave travels clockwise from the clamp, and the other travels counter clockwise. Each wave is reflected by the clamp at the bottom when it has gone completely around the circle.

At most frequencies the crests of the waves traveling in one direction will not coincide with the crests of the waves traveling in the other direction. The many waves will cancel each other's effect, and the ring as a whole will not show much effect of these waves.

At selected precise frequencies, however, the crest of all the waves, reflected as well as original, will coincide at certain positions around the ring. The cumulative effect will add to produce bulges in the ring at these places. The vibration can then become very large. The rings "resonate" at these particular precise frequencies.

It takes more force to bend the steel near the clamp at the bottom than it does at a distance from the clamp. As a result, the waves do not travel at a uniform speed around the ring; they slow up near the top. The frequencies at which the rings resonate therefore increase more rapidly than one might expect. The smallest ring is only about half the size of the largest, but its lowest resonant frequency is three times the resonant frequency of the largest one. Similarly, the frequencies of the harmonics are not simple multiples of the frequency of the fundamental (3, 5, 7) but the less obvious (3-1/2, 7-1/2, 13). A musical instrument with such overtones might sound quite strange.

Black Sand

Description

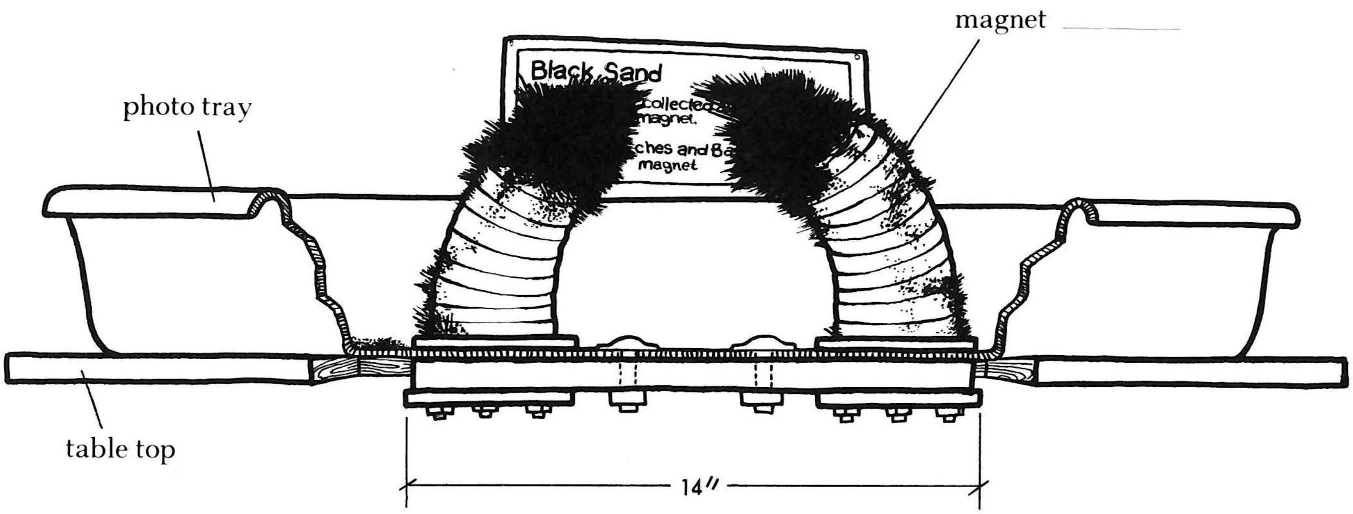
Magnetic lines of force can be seen and felt using a large magnet and several pounds of black sand (magnetite) or iron filings. The sand follows the magnetic lines of force and can be made to form images of the magnetic field. The sand, (without dirtying one's hands) provides a very pleasant and unusual tactile sensation because of its attraction to the magnet. Magnetic "castles of sand" can also be built.

Construction

A large 24"x28" photographic tray is bolted onto a table and the magnet is firmly bolted through holes cut in the tray and table to its iron base. We have increased the distance between the pole pieces to about 5" to allow better access to the strongest part of the field. The magnet is a large war surplus radar gap magnet. We have also obtained similar magnets that were used to bend beams of particles from the former California Institute of Technology Synchrotron. The sand is obtained from a local beach and is sorted to rid it of non magnetic material with an electromagnet made from an iron bar and wire coil. The proportion of black sand to normal sand varies seasonally with more black sand appearing during stormy weather.

Critique and Speculation

The type of magnet used in this exhibit is getting very difficult to find as surplus supplies dry up. It might be possible to substitute one of



the newer types of rare earth magnets which are very powerful for their weight (we have not researched this possibility). The only problem with the exhibit itself is that the sand tends to get thrown around and ends up on the floor (and hence needs replenishment now and then). This can make quite a mess and must be cleaned up often if it shows on the floor (our floor is asphalt so it isn't too bad). Perhaps a large tray could be built with raised edges (that wheelchairs can roll over) to catch the wayward sand. This would allow re-cycling of it at the end of the day. This tray would have to be rather large (at least 8'x8') to catch most of the sand.

Additions and Changes (1990)

We have added a ledge around the inside of the tray, and it helps keep the sand in. But you should be careful to keep this exhibit away from computers, aquariums, and electronic exhibits that might be harmed by iron sand.

If you don't have access to black sand, David Sprankle of the Louisville Museum of History and Science reports successfully substituting the small steel shot used in sandblasting. He used the smallest size available. Sprankle reports that the feel of the steel shot is different than the sand, but that it seems to work fine. We haven't tested this ourselves.

Related Exploratorium Exhibits

ELECTROMAGNETIC FIELDS

Circles of Magnetism I, II, III, IV

MAGNETS PERMANENT

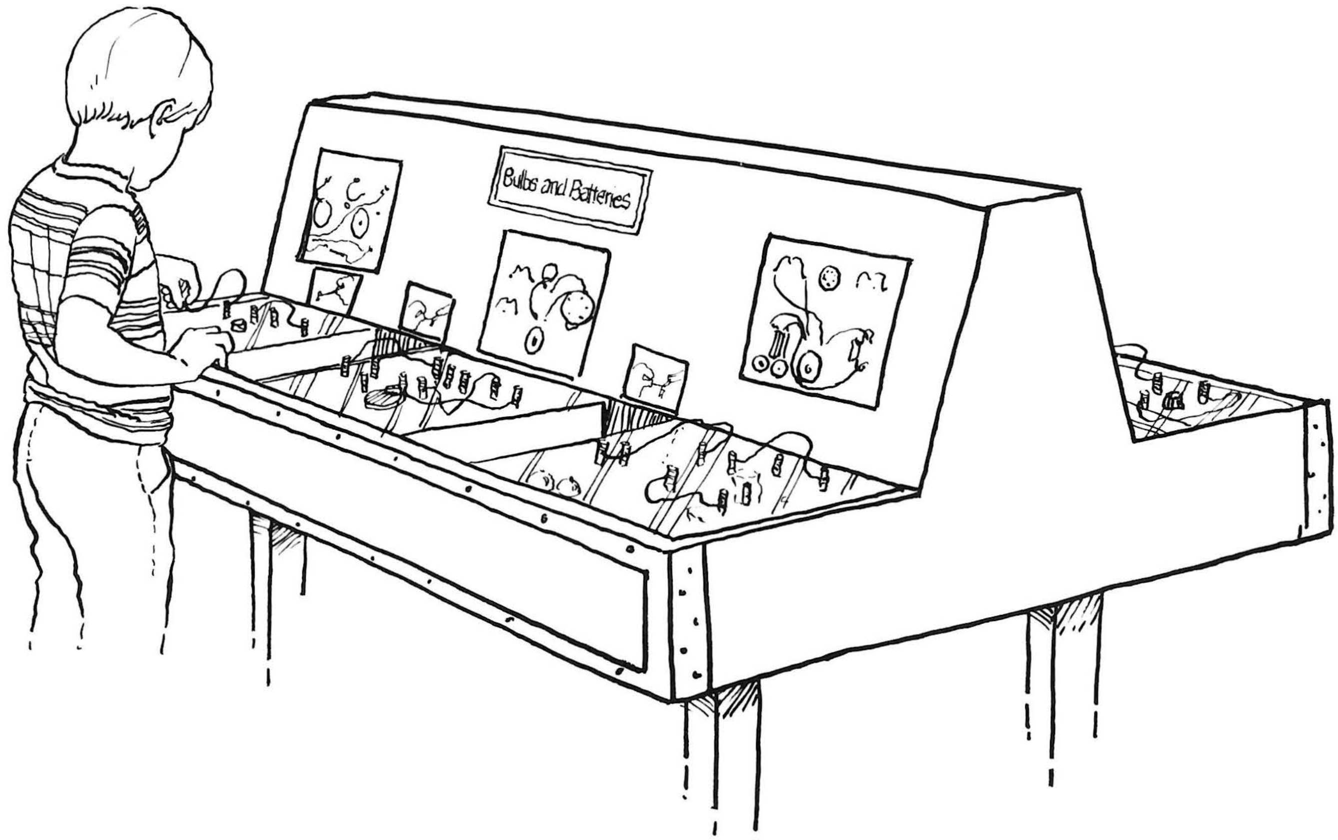
Magnetic Lines of Force

Exploratorium Exhibit Graphics

This sand was collected at Ocean Beach with a strong magnet.

Keep your watches and Bart tickets away from the large magnet!

Bulbs and Batteries

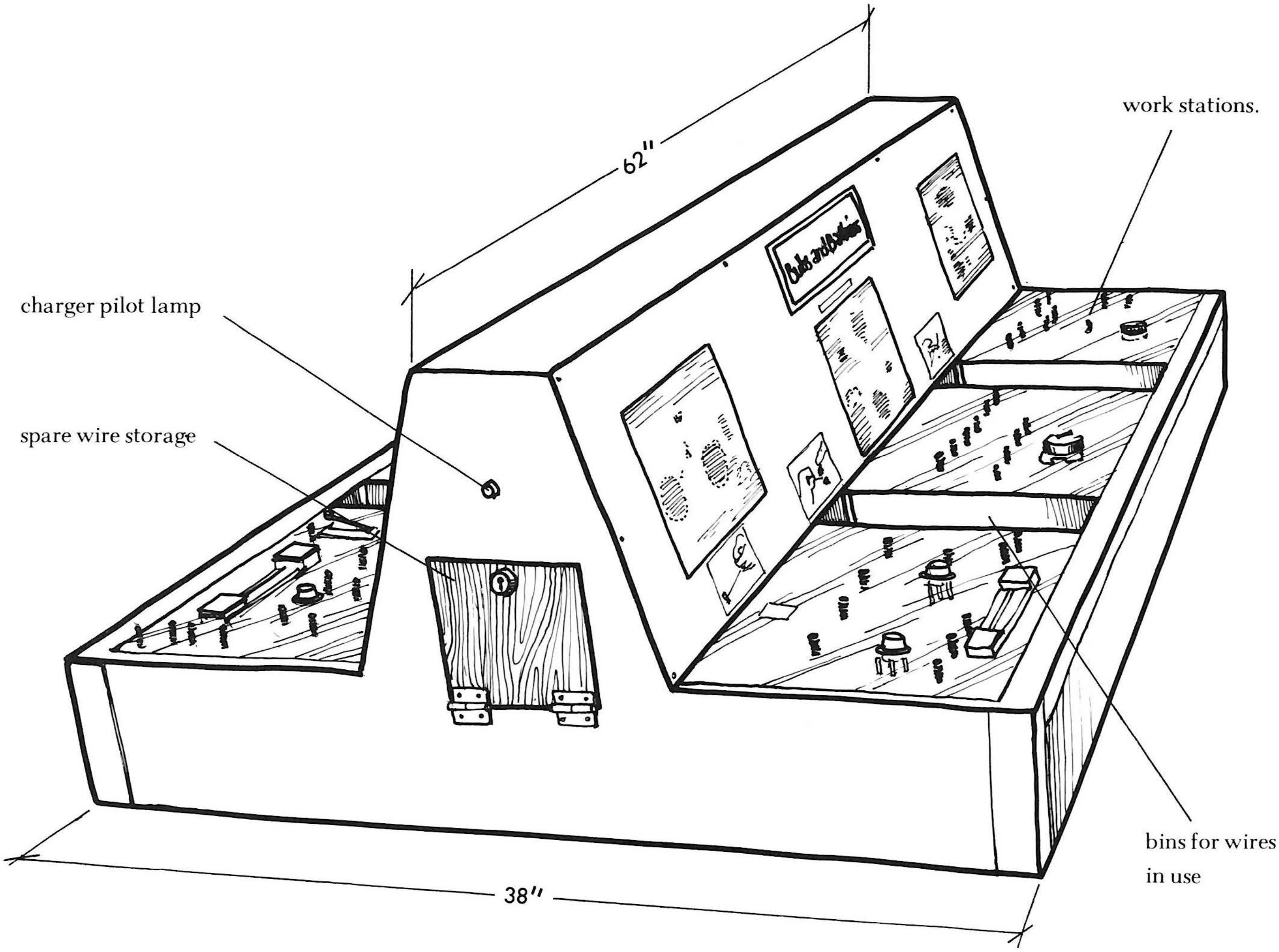


Description

This exhibit lets people experiment with electrical circuits by allowing them to construct simple circuits of their own design. Insulated wire with stripped ends is supplied to make the connections between various pieces of electrical gear housed under clear plastic with their terminals sticking through. A couple of example circuits are shown in the graphics to get the person started. The experimenter is encouraged to try his own ideas out to see if they will function.

Construction

The exhibit is divided into six work stations, three on each side of the table. The different stations have different devices to work with (see detail), with four stations containing batteries for power and the remaining two a hand cranked generator. The type of batteries we found to be most suited for the exhibit are 6V Gel Cell batteries. Two of the stations have two of the 6V batteries each (12V total if wired in series), and the other stations one battery each. The batteries are always hooked up to a charger on "float" so that they will not be discharged easily. A pilot light on the outside of the exhibit warns the staff when the exhibit is unplugged and the charger isn't charging. The hand generators are surplus bell ringing generators (used in telephone systems) made by the Kellog



Switchboard and Supply Co., Div of ITT. #G-42A/PT. These have had a 60v voltage regulator placed (inside the generator) shunting the output so the people will not get "bitten" if they connect themselves to the generator. Bins between the stations provide a storage area for the wire which has been cut to length (12"), stripped, and tinned. Approximately 12 wires per bin seem to be enough to accomodate even the most ambitious wiring project. The stock wire is stored in a locked bin inside the exhibit.

Below is a list of devices to be found in the exhibit along with any modifications we've made to them to make their operation more transparent.

● Manually operated circuit breakers (sawed open to expose the inner workings. These also protect the batteries from direct shorts and people from red hot wires if the shorts occur.

● Incandescent lamps (6 and 12 volt where appropriate)

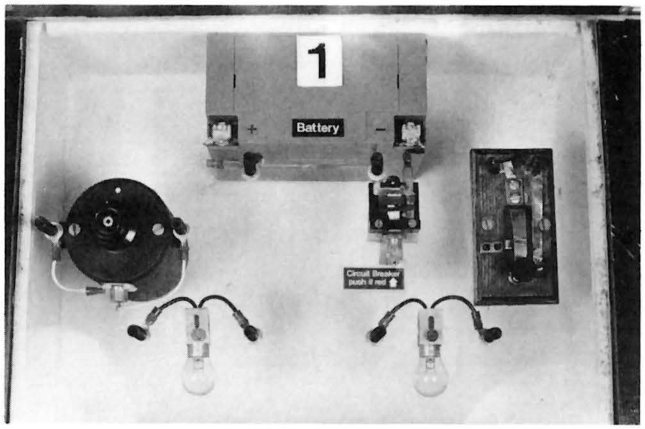
● Telegraph keys

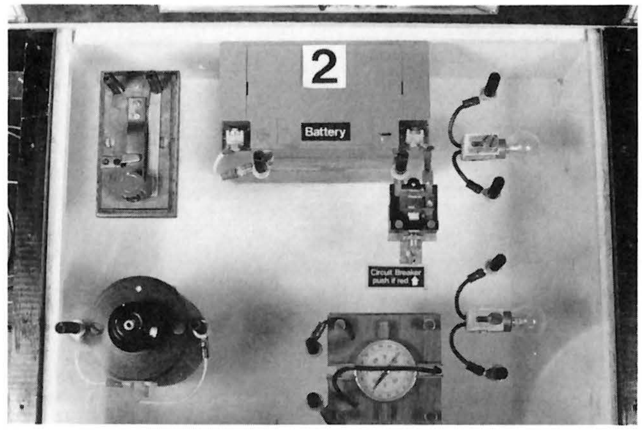
● Wall switch (sawed open)

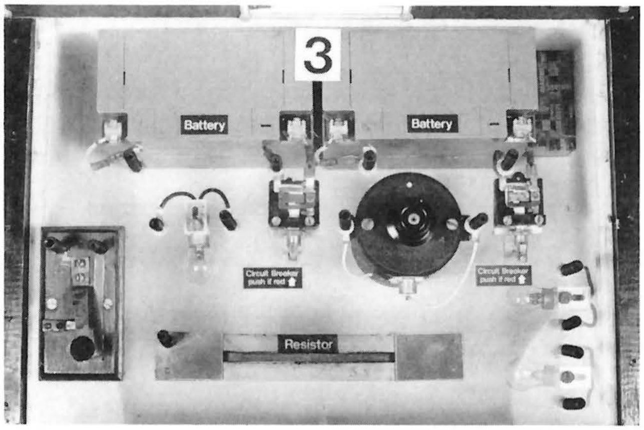
● Motors (24 volt series wound with the shaft sticking through the plastic with a knob mounted on it)

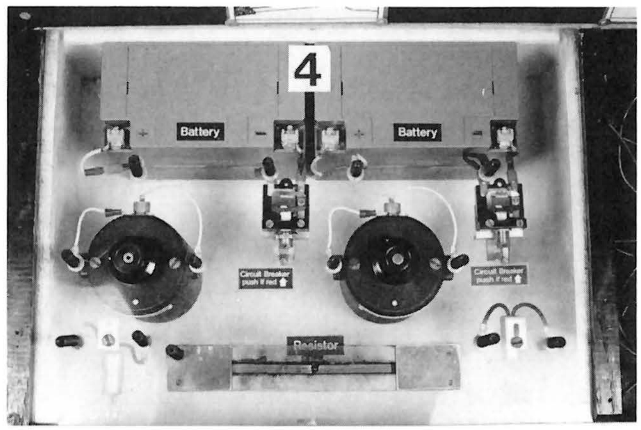
● Telephone bell (with hand generator only)

● Synchronous clock motors (with hand generator only)









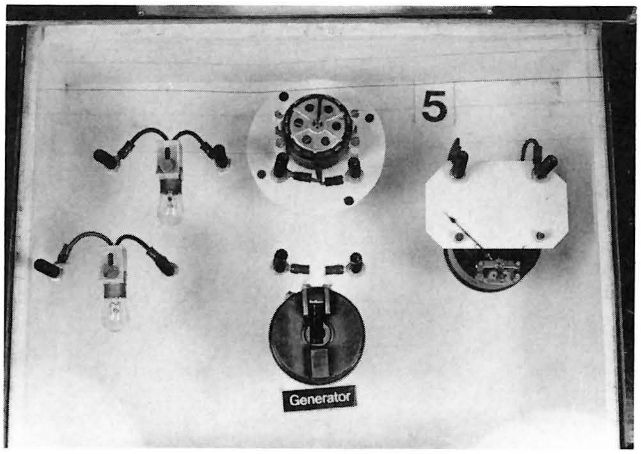
● Carbon rod resistors (Thick 1/4" square pencil leads (Kohinoor Hardtmuth #2205 2B lead)) These have a resistance of 1.5 ohms per pencil lead and we connect two in series for a 3 ohm resistor. People run the wire up and down the lead and thus have a "variable" resistor.

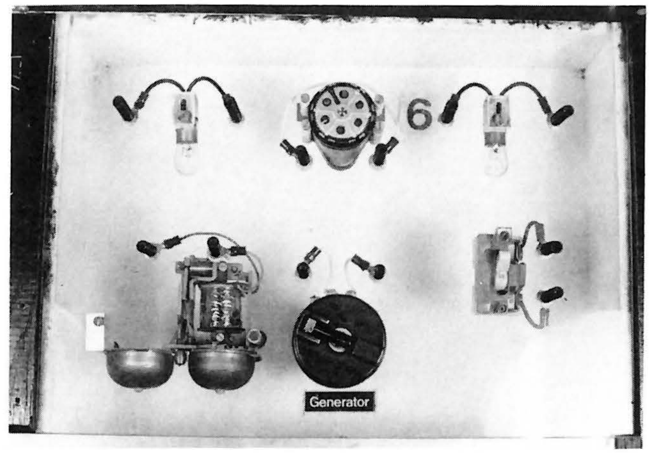
● A simple meter made from a compass with one turn of heavy guage wire wrapped around it. An FDV type projector lamp is connected in series with the coil to act as a ballasting resistor if the meter is connected directly across the battery.

The terminals which stick through the plastic are made from a stainless steel spring. The spring has an outside diameter of .315", is made of .044" wire, and has a pitch of 23 turns per inch. The 1/4" thick plastic is first tapped with a metric tap 8mm diam x .075 threads per millimeter. The 1.5" long spring is then screwed into this hole and a 1/4x20 bolt is screwed in from the bottom with a soldering lug attached (it's a tight fit!). A 1/4x20 allen screw 3/4" long is then screwed into the top of the spring to give it rigidity. To insert a wire the spring is bent back and the wire inserted into the spiral of the spring. This method has worked excellently and is very durable.

Critique and Speculation

Enterprising kids sometimes figure out that they can wire many of the



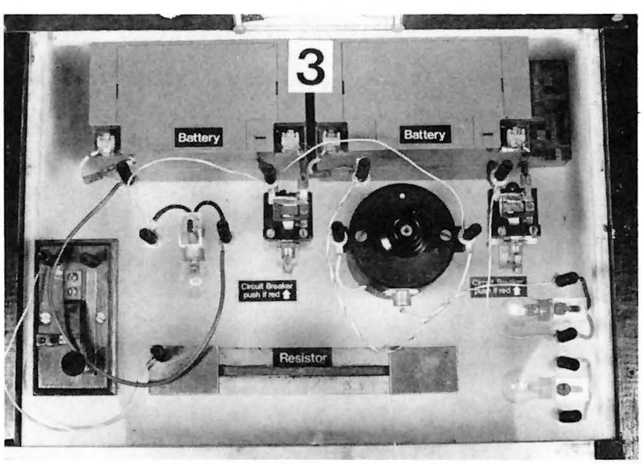


batteries in the exhibit in series and get the motors to spin faster and the lamps to glow extremely brightly (albeit for a very short time before they burn out). This problem happens infrequently enough and, since it may be educational to the experimenter, we have decided not to do anything about it except to replace the lamps when necessary.

Exploratorium Exhibit Graphics

The graphics consist of 6 example circuits, one for each work station, with a few diagrams showing how to connect the wires.

One thing to do — Try another



Additions and Changes (1990)

We found that stripping and tinning wires for this exhibit was very labor intensive. Consequently, we added a wire stripper to the top of the exhibit. Visitors can strip wire as they need it.

Related Exploratorium Exhibits

Series Parallel Circuit
DC Motor Generator I and II
Hand Cranked Generator

Photos Nancy Rodger

Recipe No. 89

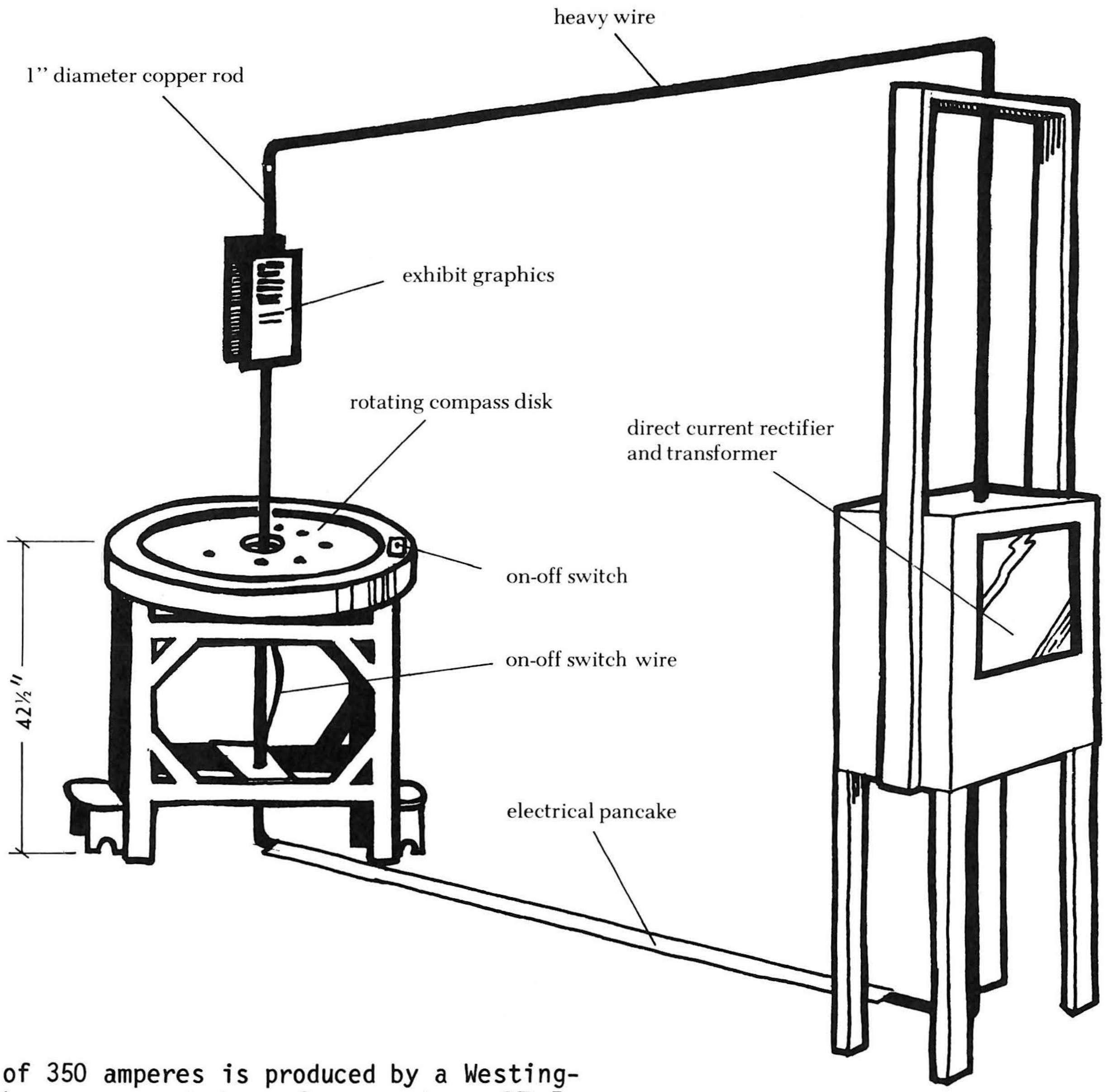
Circles of Magnetism I

Description

Circles of Magnetism shows the magnetic field surrounding a wire with a large current flowing through it. Our "wire" is a piece of 1" diameter copper rod which has 350 amps flowing through it! The magnetic field thus created causes compasses mounted in a table around the wire to line up with the field as far away as 18" from the wire.

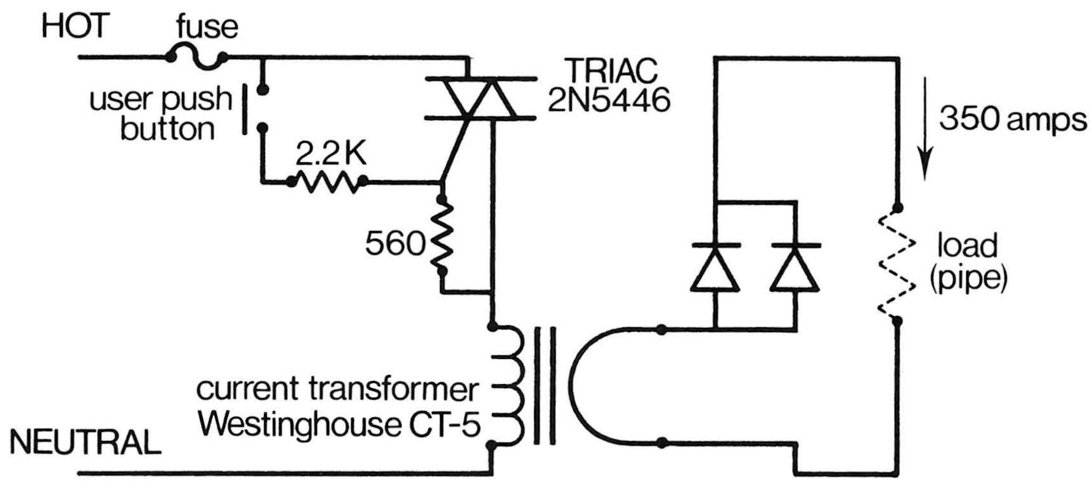
Construction

A 96" long 1" diameter copper rod runs vertically through the center of a round wooden table. Very heavy wire (350 MCM type THW) is soldered to each end of the rod and runs to the power supply. The bottom connection runs across the floor, along with wires from the "on" button, inside of a piece of electrical pancake to the power supply. The current



of 350 amperes is produced by a Westinghouse current transformer, type CT-5, with a current ratio of 300 to 5. The AC current is half wave rectified with 2 large 200 ampere stud mounted diodes mounted on cut and bent strips of copper which act as a heat sink. A fan blows air on the heat sink to keep it as cool as possible and prevent overheating.

The compass table stands about 42" above the ground near the middle of the rod (important for uniformity of the field). The 36" diameter table houses a 1/4" thick plexiglas® disk into which four circles of water filled compasses have been inset. The disk is free to rotate about the rod on top of another piece of 1/4" white plastic. This feature allows the visitor to "scramble" the compass needles before use. The water filled type of compass is used because it provides smooth action and is more durable. Since the table is placed so high above the ground, a step is incorporated into the base for children. The button that turns the current on is located along the rim of the table.



Critique and Speculation

The exhibit functions superbly except that the compass disk is somewhat difficult to turn as presently mounted. The ON button must be prominently labeled as it is easy to miss.

We have built other exhibits using the same type of high current transformers. One shows the magnetic field around and inside of a solenoid coil (the coil is made of copper tubing), while another shows the force between two long (12 foot) wires carrying large currents (1000 amperes) in the same and opposite directions (the conductors were made of the flexible cable used for arc welders).

Additions and Changes (1990)

The compasses eventually stop working because their pivots wear out. Replacing the compasses is rather time-consuming. We replace ours every six months or so.

Unfortunately, this exhibit is not wheelchair accessible.

Related Exploratorium Exhibits

ELECTROMAGNETIC FORCES
Earth's Magnetic Field
Circles of Magnetism II, III, and IV

Exploratorium Exhibit Graphics

To do and notice:

Slowly rotate the table top and watch the compass needles. They always point north. A few of the compass needles may have become de-magnetized and will point in some random direction. We periodically maintain the exhibit by re-magnetizing these compass needles.

Press the button near the table's edge. This will start a current of electricity flowing through the big center wire. Notice that the compass needles now form circles around the center wire.

If you rotate the table top, the compass needles will continue to "chase" each other around the circles.

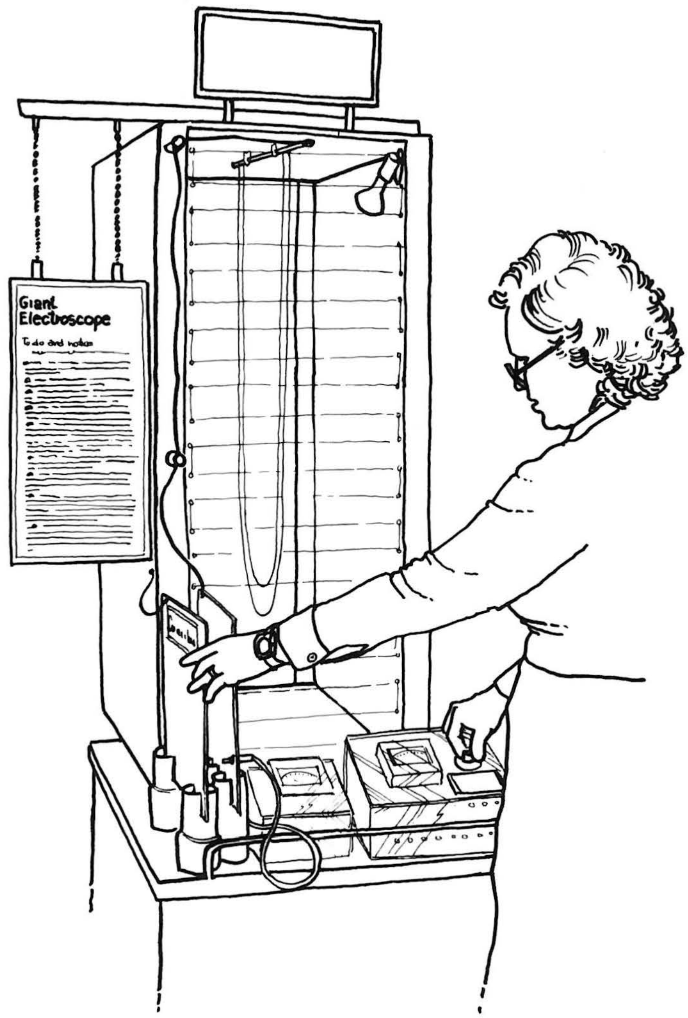
What is going on:

Compass needles are simply little magnets. When there are no other magnets nearby these needles are pushed only by the earth's magnetic field. The large current of electricity passing through the wire creates a magnetic field that is much stronger than the earth's field.

This new field is perpendicular to the flow of current in the wire. The magnetic force acts in a circular path around the wire. The force is strongest near the wire.

Recipe No. 90

Giant Electroscope



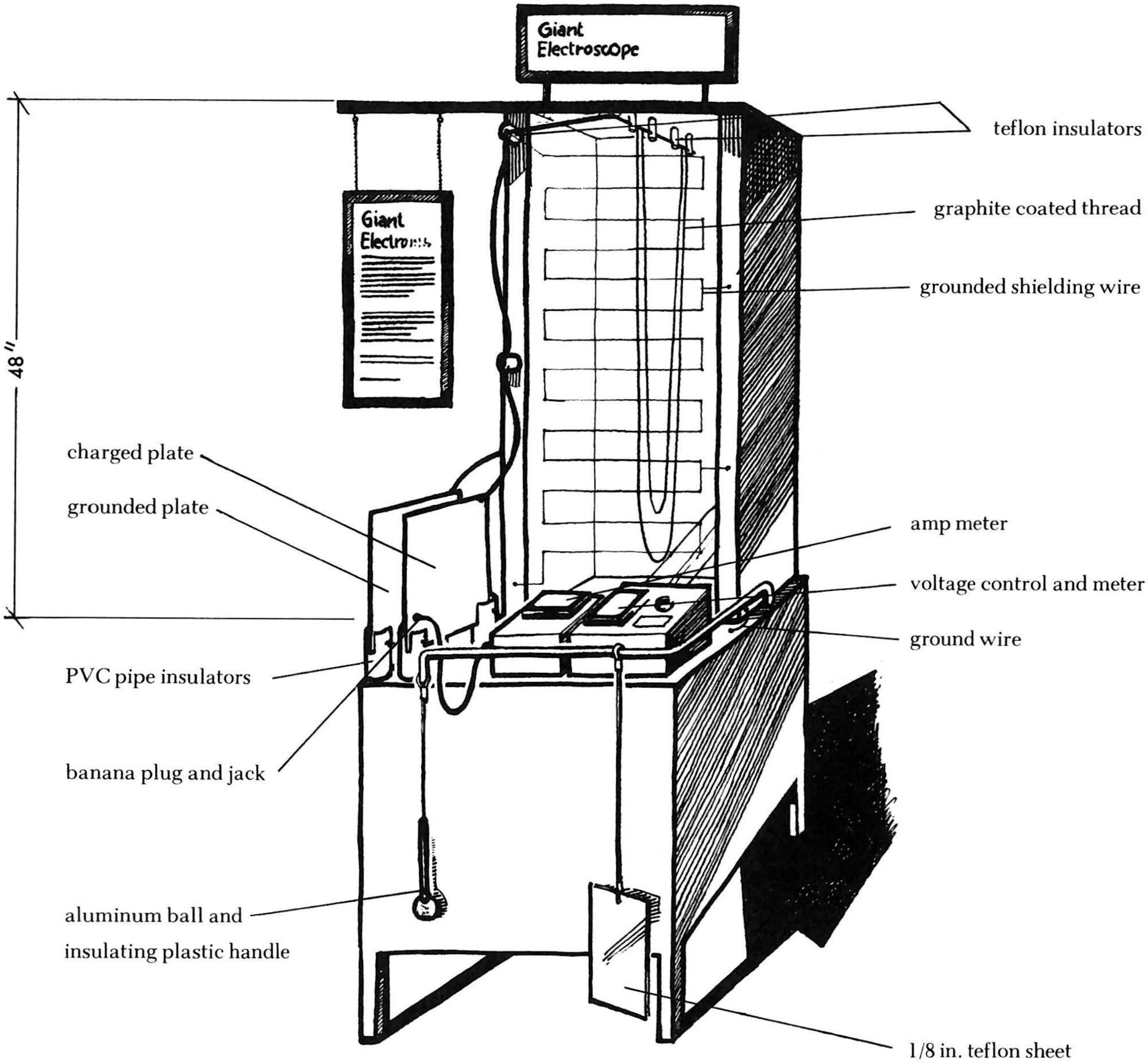
Description

Giant Electroscope allows one to perform various experiments and activities with electrical charges. A normal electroscope uses small leaves of gold (or microscopic threads of quartz) while this version uses long loops of thread which separate as they are charged up. The exhibit also allows visitors to experience small electrical shocks as they can charge and discharge themselves with the power supply provided!

Construction

The electroscope is built inside of a box with galvanized sheet metal top, bottom, and sides, a wood (masonite) back, and a plexiglass front. The plexiglass front has a wire grounded to the metal box running zig-zag from top to bottom on the inside surface which acts as electrostatic shielding in case anybody tries to charge the plastic by rubbing it.

The "leaves" of this electroscope are made of graphite coated thread, hung



in two loops, one inside the other. To coat the thread (size 50, spun polyester) a very light coat of acid soldering paste is applied to the thread. If the coat is too heavy the threads will be too heavy to separate when charged. This coating provides a sticky conductive coating onto which the graphite is then rubbed. The threads are then hung in the electroscope and checked for continuity by grounding one end and using the power supply and microammeter to check the conductivity all along the thread. Nonconductive spots have more graphite rubbed onto them to make the thread uniformily conductive along its entire length. If this is not done, there will be uncharged spots later on which will tend to twist the threads when they try to move apart.

The threads hang from a metal rod which is mounted to the top of the box with teflon stand-offs. A wire connected

to this rod runs down the front side of the box on teflon insulators to a 12"x12" galvanized sheet metal plate. This plate is mounted on PVC pipe insulating feet and bolted to the table. A similar 12"x12" plate is also fastened to the table 2" from the charging plate and grounded to form a capacitor.

The power supply consists of a high voltage transformer and rectifier which provides 2500 volts DC. A series resistor limits the current to 15 microamps. The voltage is adjustable by the user from 0 to 2500 volts. The hot side of the power supply comes out on a piece of test lead wire with a banana plug on the end which plugs into a banana jack in the charging plate. Meters indicate the voltage and the current being drawn. This voltage and current can be felt as a small shock and the user is encouraged to experiment with this aspect of the exhibit (the visitor stands on a thick rubber insulating mat in front of the exhibit).

A piece of 1/8" teflon sheet is provided to charge and compare charges by bringing it close to the charging plate and watching the electroscope. Also provided is an aluminum ball about 1.5" diameter on an insulating plastic rod which is used to charge and discharge the electroscope in small steps by touching the charging plate and then the ground plate (with the charging wire removed) repeatedly, each time removing a little charge (actually an exponentially decreasing amount).

Critique and Speculation

This exhibit is very trouble free and only needs to be cleaned of "conductive dust" every once in a while.

Related Exploratorium Exhibits

ELECTRIC FIELDS AND FORCES

Photoelectricity
Pluses and Minuses

ELECTRIC POTENTIAL

Franklin Motor
Two Plates
Pluses and Minuses

ELECTRIC SHIELDING

Photo Electricity

Exploratorium Exhibit Graphics

The effects of this exhibit are based on the fact that similar electric charges repel each other, and dissimilar electric charges attract each other. **−** repels **−**, **+** repels **+**, but **−** attracts **+**.

To do and notice:

Turn up the voltage to the full 2500 volts (25 on the meter).

Plug the red plug into the red button on the plate to the left. Notice the two looped threads in the glass case in front of you.

Notice that the electric charge on the two loops of thread pushes the loops of thread apart.

Lower and raise the voltage, and notice that the distance the threads are apart depends on how much charge you push onto the threads by the voltage.

With the full voltage on the plate, unplug the red cord. Notice that the charge stays on the plate. You can remove the charge by touching the charged plate.

After charging the plate you can also remove the charges a little bit at a time by alternately touching the charged plate and the grounded plate with the insulated aluminum ball hanging in front of the exhibit. Notice that as you take the charge off the plate, the two thread loops gradually come together.

With the full voltage you can charge the plate and the thread by alternately touching the end of the wire and the plate with the aluminum ball.

With the plates and the threads fully charged and the red wire disconnected from the plate, charge up the white teflon plate by rubbing it well on your hair or clothing.

Bring the charged teflon near the charged plate and notice that the threads come together. The rubbed teflon is negative (-) and the plate is positive (-). The charged teflon pulls some of the - charges away from the threads and thereby reduces the force with which the two loops are pushing on each other.

With the plate uncharged with full voltage on the wire, look at the milliammeter closely while touching the plate with the end of the wire. Notice that a small current runs momentarily while the plates are charging up.

Small Shock

With the voltage all the way up and the wire plugged in, touch the charged plate with one finger and then touch the grounded plate with another finger of the same hand, and you will feel a small shock as the electric charge runs through your fingers and onto the grounded plate.

When you are standing on the mat watch the meter when you touch the charged plate with one finger. You will see a momentary surge as the charge runs onto your body. When you then touch the grounded plate a very small steady flow of charge runs through your fingers.

Recipe No. 91

Hand Battery

Description

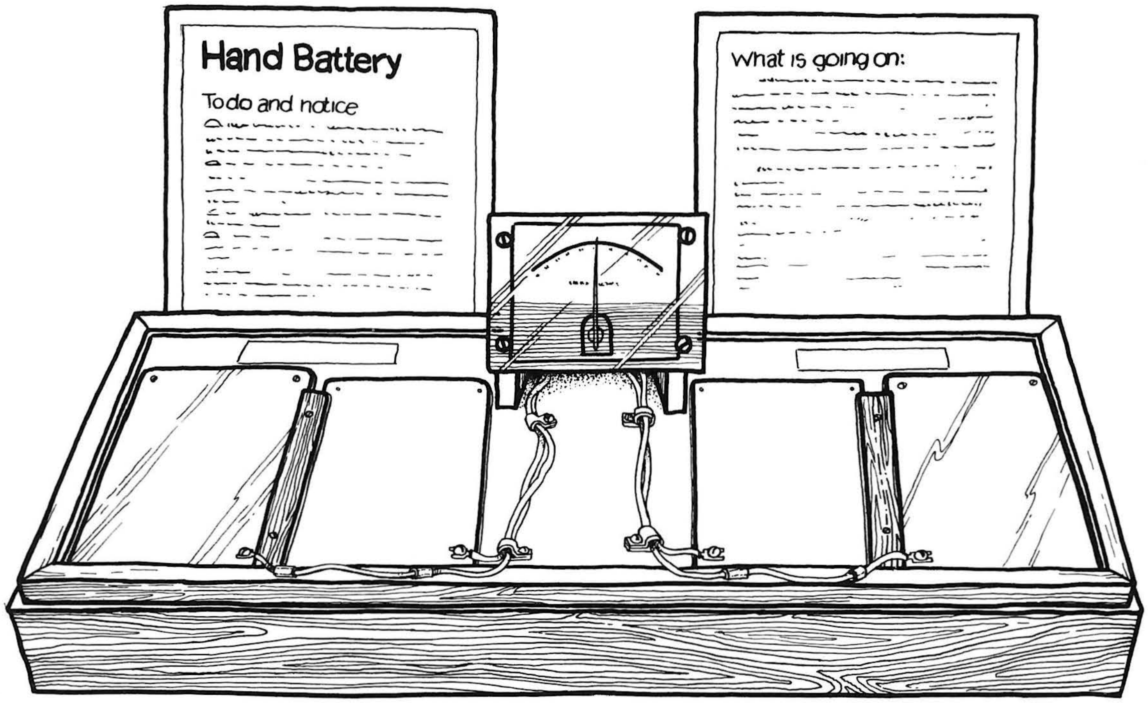
The salty dampness of the visitors hands coming into contact with copper and aluminum plates creates an electrochemical reaction resulting in a small current which is registered on a meter. The wires between the plates and meter run on the table top to show the interconnections clearly.

Construction

Four metal plates are screwed to the table top and wires (with spade lugs on the ends for ease of connection) run from these to the meter along the top of the table held down with cable clamps. Two of the plates are aluminum and the other two are copper, arranged and wired as shown in the diagram. The meter is a 200 microamp center zero meter. The center zero feature is essential to show current flow in both directions.

Critique and Speculation

This is a very popular exhibit and every once in a while the wiring gets pulled on and must be repaired or replaced. The plates also tend to get dirty and corroded when the exhibit isn't used and must be cleaned with steel wool(our environment is damp).



aluminum copper copper aluminum

Related Exploratorium Exhibits

ELECTROCHEMICAL EFFECT
Taking Water Apart

Exploratorium Exhibit Graphics

To do and notice:

Put your left hand on the aluminum plate and your right hand on the copper plate. An electric current flows which you can observe on the meter.

Try various combinations, such as copper and aluminum, copper and copper, etc. In order to get clear indications on the meter you may want to rub the plates with your hands.

Try making your hands moist by breathing on them. Does this have any effect on the meter current?

Try touching the copper and aluminum plates with one finger of each hand at a time, then two fingers, and three, etc.

Have one person put a hand on the copper plate and another person put one hand on the aluminum plate and then join hands together.

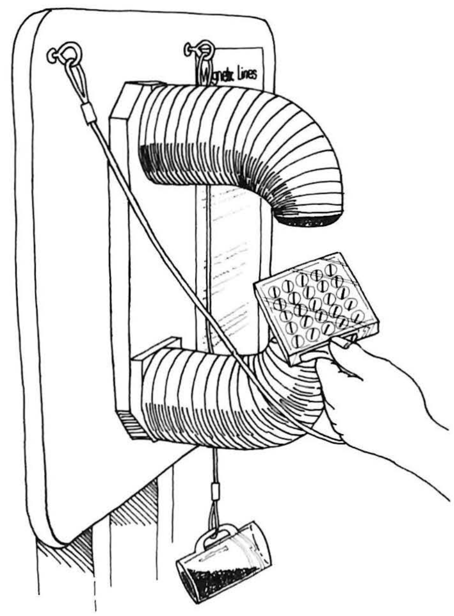
What is going on:

Your body acts like the acid in a battery. A different chemical reaction takes place when your hand, which is slightly damp and salty, touches the copper plate than when your hand touches the aluminum plate. One of these reactions takes electric charge away from the copper plate, and the other reaction adds charge to the aluminum plate.

The excess electric charge on the aluminum plate then flows through the meter and then back to the copper plate to equalize the charge which is missing there. At the same time the extra charges which have accumulated on one hand flow through your body to the other hand.

The current is so small that you cannot feel it. It is kept small because your skin, especially when it is dry, resists the flow of current. The energy to maintain this current comes from the chemical reaction between the metals and the fluids in your body.

Magnetic Lines of Force



Description

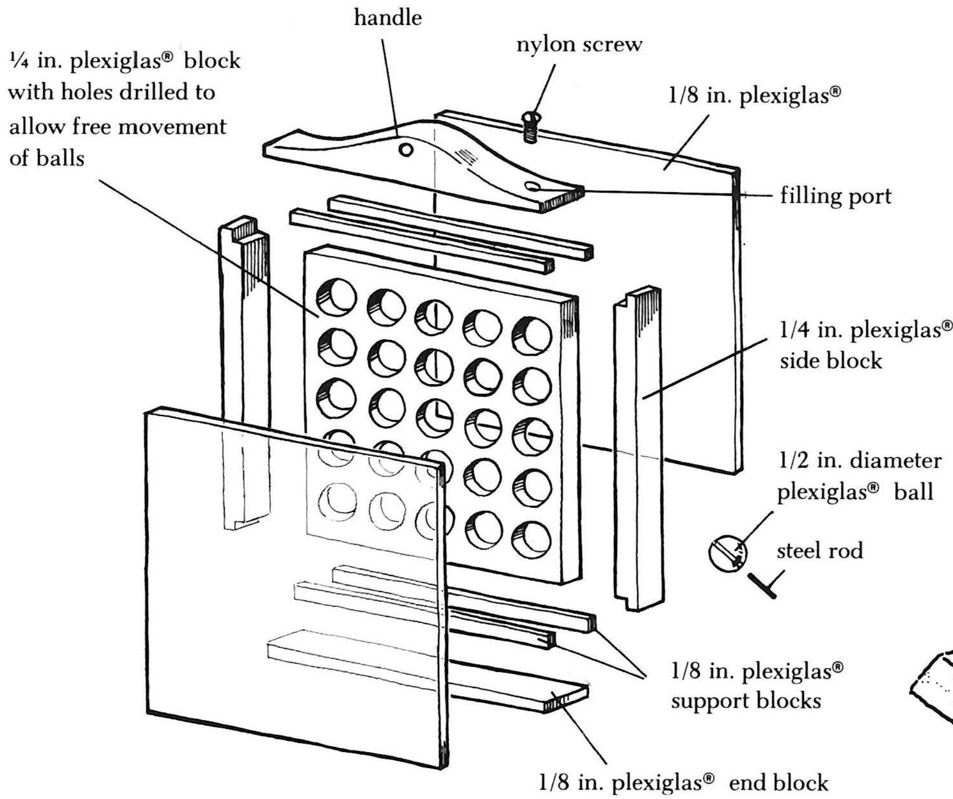
The mysterious field surrounding a large gap magnet can be explored using a clear plastic cylinder containing magnetic sand or with a plastic block containing freely rotating plastic balls with steel rods implanted in them causing them to "follow" the magnetic field.

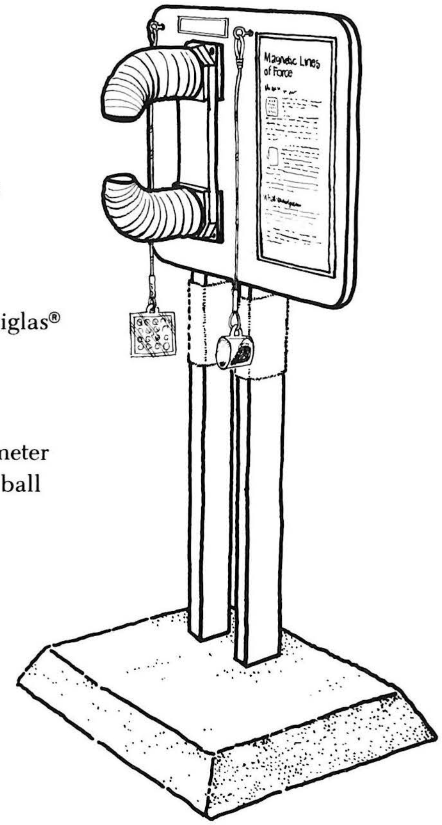
Construction

The magnet (a typical World War II radar magnet) is bolted firmly to a wooden backboard which also serves to hold the exhibit graphics. This board is mounted to a very heavy base to keep the exhibit from tipping over (a heavy magnet falling on toes tends to be very painful). Both the cylinder of black sand (magnetite gathered at the local beach, or iron filings as a substitute if sand is unavailable), and the ball-block hang from the backboard from stainless steel cables.

The cylinder must be made to fit within the gap of the magnet (ours is 4" long and 2.75" OD). It is made of plexiglas® tubing with a 1/8" wall. The top and bottom are cut from 1/4" plexiglas® sheet to the OD of the tube and a step machined in each disk to fit within the tube. One end is glued on with solvent cement and allowed to dry. A 3/4" high fill of black sand placed in the tube and the other end then glued on. An eyeloop of plastic is cemented onto the side of the tube and attached to the steel cable.

The ball-block is formed from a "sandwich" of several layers of plexiglas surrounding the balls (see exploded diagram). The whole assembly is cemented together with solvent cement (be careful not to dribble cement into ball chamber). The balls were purchased from a plastics company and are 1/2" in diameter. We drilled 1/16" holes through their centers and press fit slightly crimped pieces of 1/16" steel welding rod into the holes. Before filling the chamber with mineral oil, the block must be annealed for 12 hours at 175 degrees Fahrenheit in a oven. This process





increases the strength of the block by a factor of two. The chamber is then filled through a filling port previously drilled into the side of the block and stoppered with a nylon screw threaded into the hole.

Critique and Speculation

One possible difficulty in building this exhibit is finding the magnet. You may be able to substitute one of the newer rare earth magnets or even an electromagnet for our radar magnet.

Related Exploratorium Exhibits

MAGNETIC FIELDS
Black Sand
Circles of Magnetism I, II, III, and IV
Magnetic Tightrope

Exploratorium Exhibit Graphics

To do and notice:

This device contains short iron rods which are mounted in plastic spheres which are free to rotate so that the iron rods can align themselves along the direction of the magnetic field.

Move this device around and in between the pole faces. By moving it around you can see that the lines of magnetic force from the center of the poles are straight while the lines around the outside are curved.

Put the container of black sand between the poles of the magnet and watch the sand react to the field. The black sand is an iron oxide compound. Each particle becomes a small temporary magnet when in the magnetic field and tends to clump where the field is strongest.

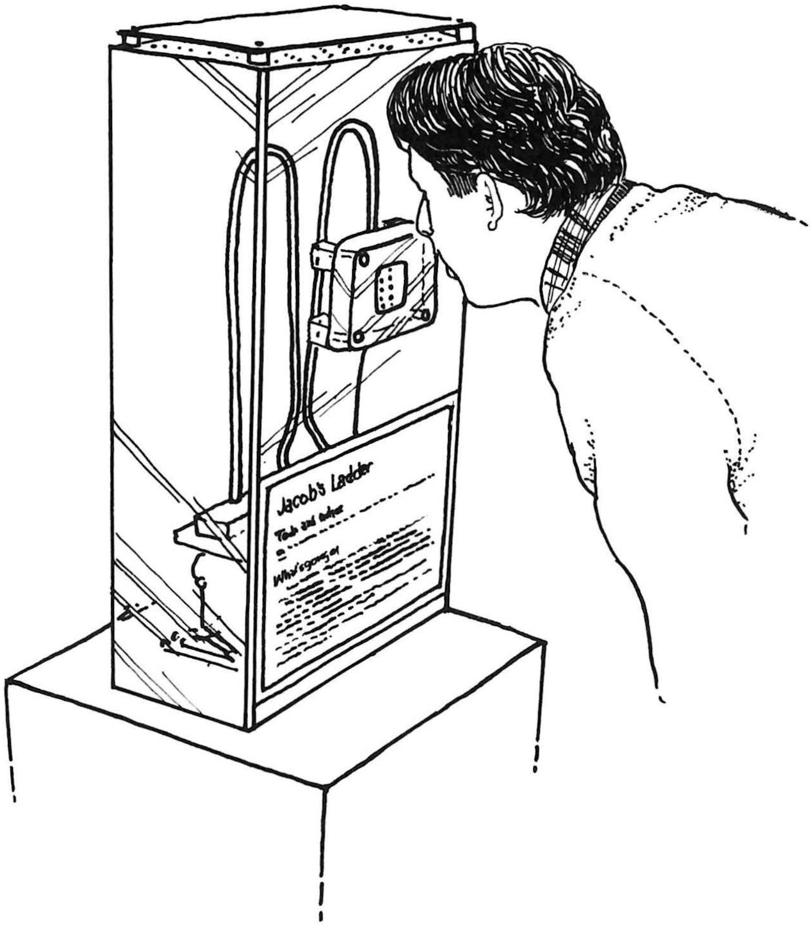
The magnet came from the California Institute of Technology Synchrotron, and the black sand came from Ocean Beach.

What is going on:

The magnetic field is an abstract idea which describes the space around a magnet. At every point of this space the pole of the small magnet will experience a force which has a particular size and direction.

There are no actual lines in this space, but it can be represented by drawing lines which show the direction of the force at every point in the magnetic field.

Jacob's Ladder

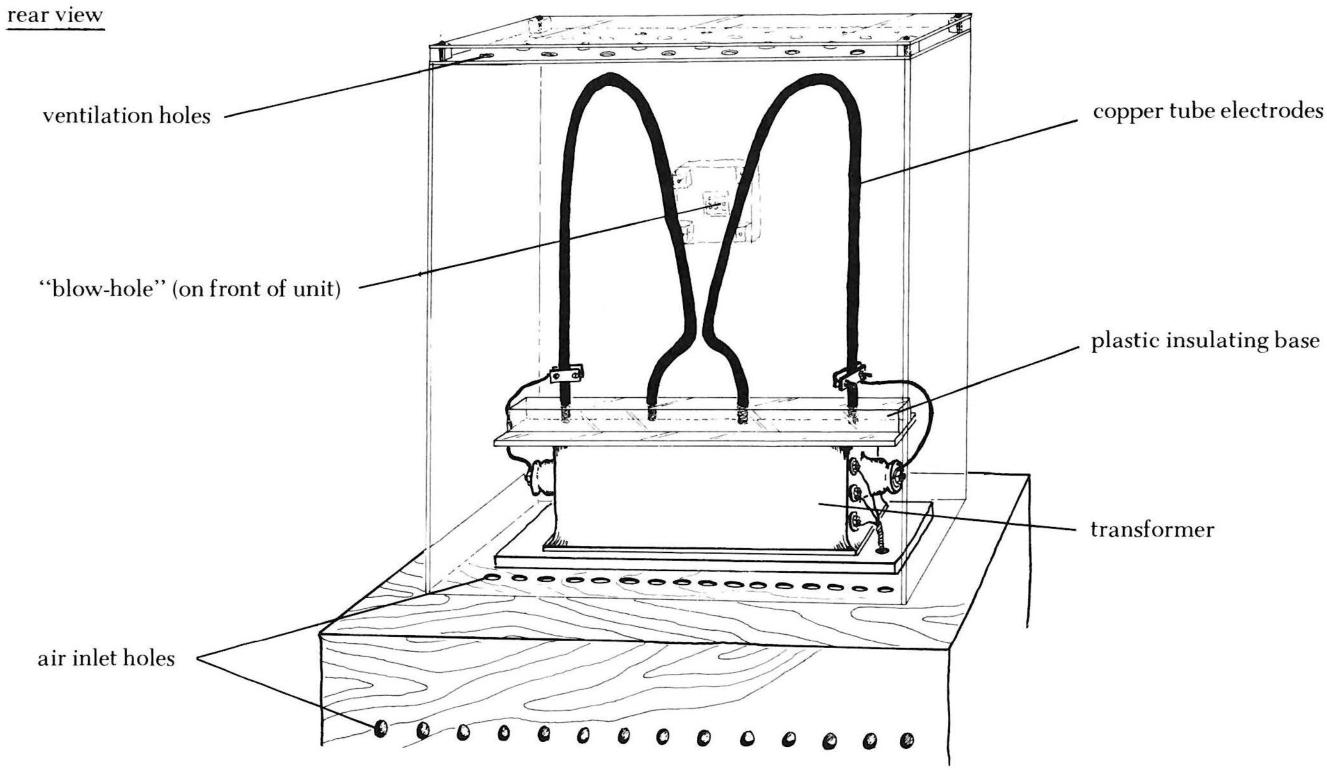


Description

The Jacob's Ladder is familiar equipment to all science fiction fans, being standard laboratory apparatus for all mad scientists. A small spark starts at the bottom of a pair of "V" shaped electrodes, traveling up and getting larger as the space between the electrodes widens. The spark pops off at the top and the cycle repeats over and over.

Construction

A high voltage (15000 volts at 40 mA) neon sign transformer, which is self current limiting, supplies the necessary current for the spark. The electrodes are formed out of copper tubing, set in a block of plastic for insulation. The electrode assembly sits on top of the transformer connected to it with wire. Copper tubing was chosen for the electrodes for its durability and rigidity. The transformer and electrodes sit on a wooden pedestal covered by a plexiglas box. The top of the box is drilled with many holes for ventilation and a piece of plastic is spaced over these holes to prevent people from sticking objects into the box. Air enters the plastic box through holes in the pedestal (top and back). This ventilation is necessary because of the great amount of ozone produced in the spark. A hole is drilled in front of the plastic box and a block of plastic drilled with many small holes



is bolted over the large hole. This opening allows the user to blow the spark out with a bellows hanging from the exhibit. A mat switch in front of the exhibit along with an associated triac circuit (a relay could be substituted except for the ozone problem) turns the exhibit on when someone is standing in front of it.

Critique and Speculation

As with any exhibit employing high voltages, adequate precautions must be taken to protect the uninformed user from coming in contact with the high potentials. Signs and guards should always be used, leaving no exposed or accessible high voltage.

Related Exploratorium Exhibits

ELECTRICAL FLOW THROUGH GASES

A.M. Lighting
Franklin Motor
Glow Discharge
Quiet Lightning
Slow Motion Switch
Spectra
Tesla Coil
Iron Sparks
Electric Flame

Exploratorium Exhibit Graphics

To do and notice:

Step on the mat and watch the electric discharge between the two copper rods rise and go out.

What is going on:

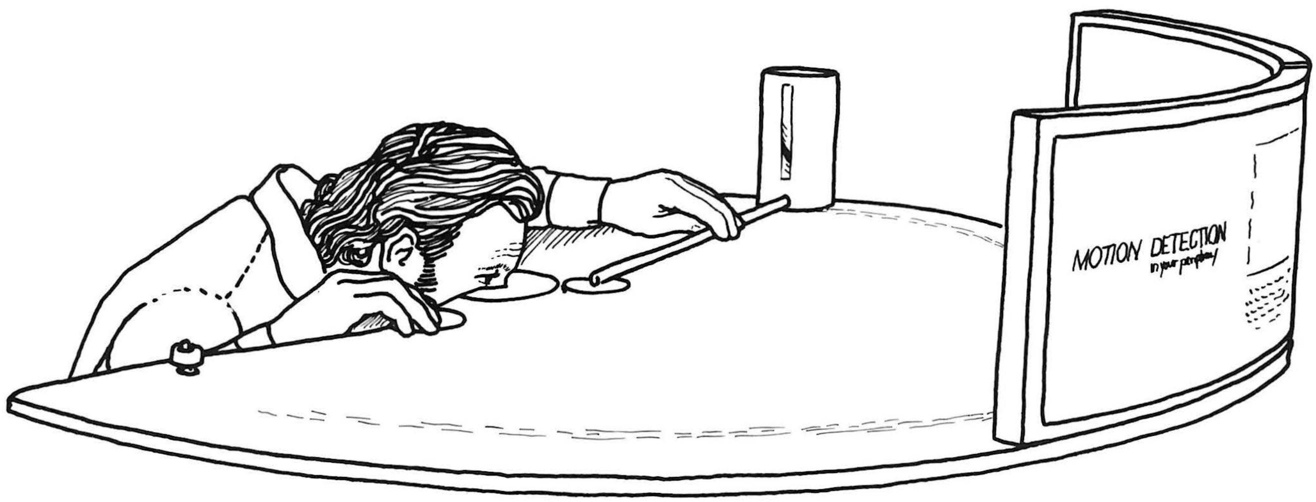
The 110 volt house current is raised to high voltage by the same kind of transformer that is used in neon signs. This high voltage occurs between the two copper rods.

The electric forces due to this high voltage difference between the two copper rods are strongest at the bottom where the copper rods are close together. These forces are strong enough to tear apart the atoms in the air into electrically charged fragments which carry the electric current between the two rods.

The recombination of these electric fragments in the air also produces light and heat. The hot air rises carrying the electric fragments with it.

If you blow on the air, you blow the electrified fragments away and the arc stops. A new one forms again at the bottom.

Motion Detection

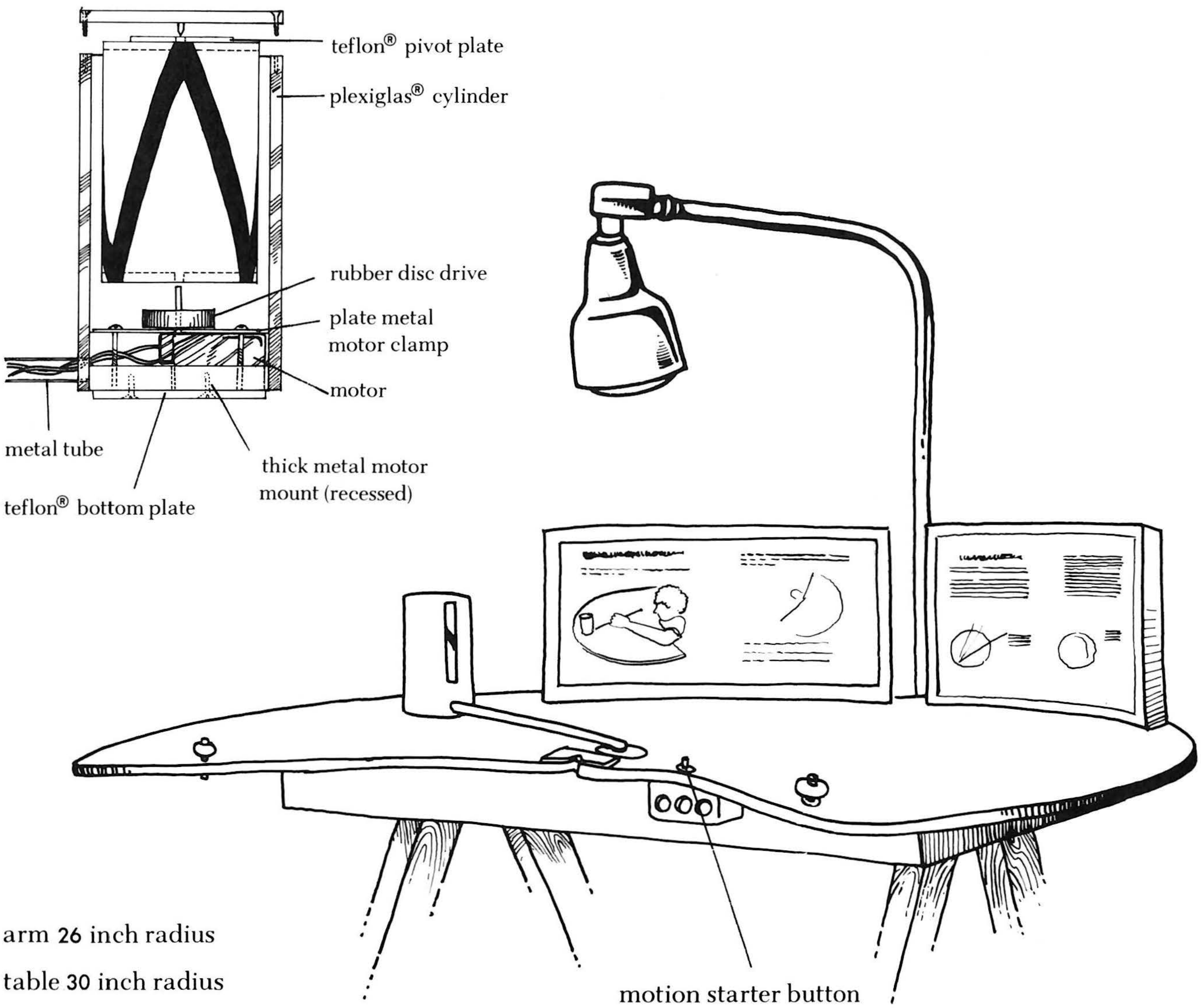


Description

This exhibit demonstrates detection of motion in a person's peripheral vision. The subject sits with his head at the center of a large semicircle. An object which can be either moving or stationary can then be adjusted around the edge of the semicircular table until the object disappears in the users peripheral vision. The user subsequently becomes aware of the object when motion is introduced. The moving object is much easier to detect.

Construction

The large plywood semicircle is mounted on a sawhorse stand high enough to make it comfortable for the seated person to put his/her head at the center of the circle. A barrier around part of the outside perimeter of the semicircle shields the user from outside distractions as well as serving to hold all of the graphics. The viewing object consists of two cylinders, one nested inside of the other, mounted to a steel tube and pivot so the object may be swung in an arc around the circumference of the semicircle. Rubber bumpers stop the object at the limit of the swing. The inside cylinder is white with a zig-zag black stripe painted around it and the outside cylinder made of plexiglass and painted opaque white except for a clear slit which faces the center of the table. The inside cylinder is then rotated within the other by a small synchronous motor at about 60 rpm making a small black spot (a piece of the zig-zag) seem to bounce up and down in the slit. Wiring is passed through



the steel tube and pivot. A button on top of the table turns the motor on. The table is illuminated from above with a 150 watt floodlamp located over the user's head to provide uniform lighting around the periphery of the exhibit.

Critique and Speculation

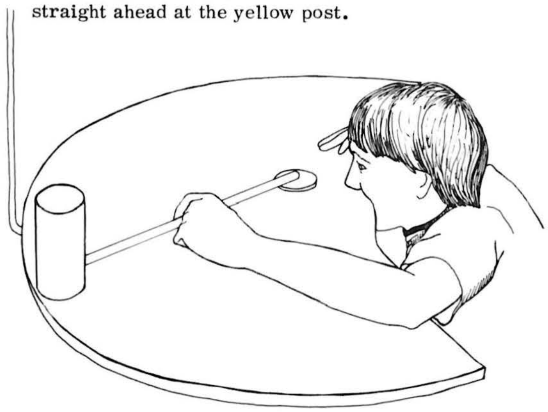
The only difficulty we've had with this exhibit is that people have to grab the steel tube to move the object with the result that their hands get in the way of what they are supposed to see. The same is true for the button on the table top. The user should be able to pivot the object from beneath the table, perhaps with a lever or steering wheel. The button could also be placed under the table.

Related Exploratorium Exhibits

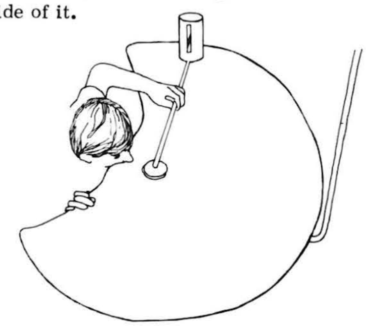
Peripheral Vision
Watchful Grasshopper

TO DO AND NOTICE

Put your face up to the edge of the table and look straight ahead at the yellow post.



Continue to look at the yellow post and move the white cylinder to one side until you can no longer see the black diagonal line inside of it.

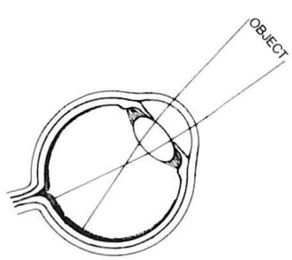


Push the MOTION STARTER button on the table to your right.
You can detect the movement of the diagonal line even though you can not see it when it is standing still.

WHAT IS GOING ON

Motion detection is an aspect of vision. In the extreme periphery of your vision where you can not see anything in detail, you can detect motion. It is thought that there are special cells in the eye and brain that are only sensitive to movement.

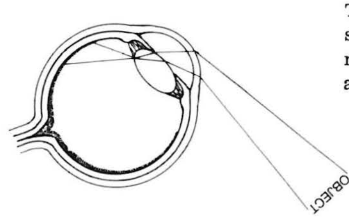
You can clearly see the detail, movement, color and shape of an object located directly in front of your eyes.



The image of the object is focused on the back of the eye where there is a high concentration of receptor cells.

Objects which are located in your peripheral field can be seen for color , shape, and movement, but detail is fuzzy. See a related exhibit PERIPHERAL VISION, for the degrees of which you can see in your periphery.

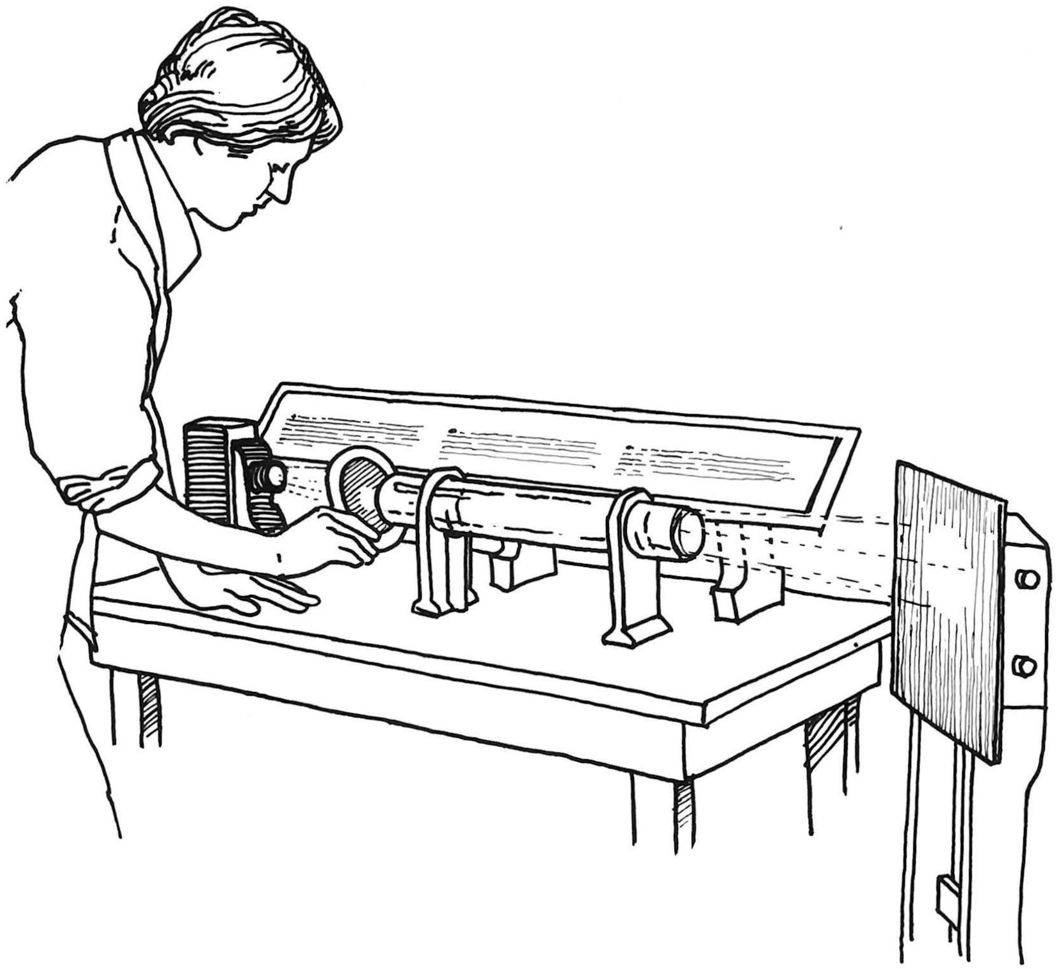
An object located in your extreme periphery where you can not see it s detail, color, or shape, is partially focused on the side of your eye where there are fewer receptor cells.



These cells require a stimulus such as motion in order for an object to be seen.

See the back of this sign for more information about motion detection.

Blue Sky



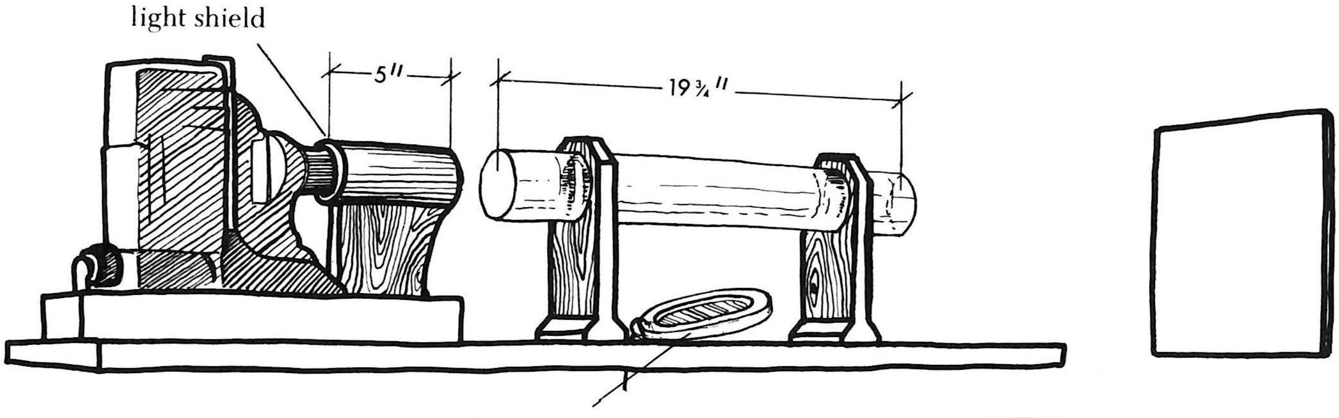
Description

This exhibit provides a model showing why the sky is blue, a phenomenon called "Rayleigh scattering."

A clear tube is mounted in front of a light source with the light shining into the end of the tube. The light scattered by the gelatin in the tube looks blue near the projector and becomes progressively more orange down the tube. An orange "sun" emerges from the tube and is projected onto a screen on the side of the exhibit. A polarizing filter is attached to the exhibit table so the user can experiment with the polarized properties of scattered light.

Construction

The most important part of this exhibit is the scattering tube. It is made of plexiglass tubing, 19.5" long and 2.5" outside diameter with a 1/4" wall thickness for strength. Both ends of the tube have plexiglass windows solvent cemented into place and a filling



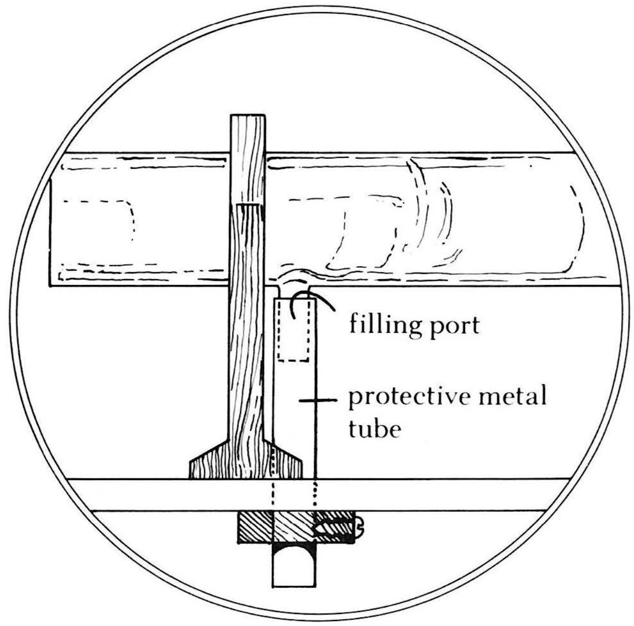
port is drilled into the side of the tube near one end. A 2"i.d. by 2.5"o.d. ring of black paper, at the projector end, prevents light from travelling down the walls of the tube. The tube is vented as illustrated and is filled with 8AP 300 Blume type gelatin. We have had excellent results with the following formula:

43.2 gm 8AP 300 Blume
1800 ml Sterile distilled water
7.5 gm Sodium Benzoate (as a preservative)

First wash anything which will come into contact with the gelatin with a concentrated solution of sodium benzoate. This will sterilize the components and prevent growth of mold (which thrives on gelatin). Mix the ingredients cold and let stand for 15 minutes. Heat in a double boiler to 65 degrees Celsius. Fill and cap the tube.

Ordinary "Knox" gelatin (or even lemon Jello in a pinch) can be substituted although we have obtained the best results with the formula above.

The light source was made from an old slide projector by replacing the old lamp with a tungsten-halogen projector lamp type ENH. This lamp has superior color balance and with the addition of one layer each of Gelatran light pink #03 and steel blue #73 filters (available from theatrical supply houses) the color was balanced to the desired value (a little less yellow). The lens was



detail of filling port in down position

then replaced with an old Kodak Carousel 5" focal length lens and a circular aperture placed in the slide gate.

The polarizing filters (2 ea) are mounted into circular masonite frames and secured to the exhibit table with steel cable.

Critique and Speculation

The gelatin slowly loses water to the atmosphere through the air vents. When this happens (every 4 to 6 months), the tube is placed in the oven at 60 degrees Celsius to melt the gelatin and bring the bubbles to the filling port. The void left by the bubbles is then

filled with sterile water.

Additions and Changes (1990)

After we built this exhibit, our original gelatin supplier went out of business. We had a small stock of gelatin on hand and have not yet had to experiment with other gelatins. However, we have found another supplier of 300 Blume gelatin:

Bryant Labs
1101 Fifth St.
Berkeley, CA 94710
(415) 526-3141

We have not yet tried their gelatin.

Our original design included a free-standing screen on which the orange "sunlight" could shine. We have now hinged a screen to the end of the exhibit, since the free-standing screen often became separated from the exhibit.

Related Exploratorium Exhibits

SCATTERING AND POLARIZING

- **Sun Painting**
- **Polarized Sunglasses**
- **Polarized Light Island**

Exploratorium Exhibit Graphics

To do and notice:

If you look into the tube from the right end you will see the orange light of a sunset. In this exhibit we have tried to simulate the conditions of the atmosphere. Imagine that the white light coming in from the left represents a beam of sunlight. The material in the long plastic cylinder represents the atmosphere. This material is ordinary gelatin. The groups of molecules in the gelatin are large enough to scatter the light.

If you look at the tube from the side you will see that the blue part of the white light is scattered first. This shows you why the sky is blue. After most of the blue is scattered out, the remaining colors continue to scatter out of the beam as the light continues down the tube. This accounts for the fact that the sun is not only redder but also not as bright at sunset as during the day.

Look at the beam of light in the cylinder either from the side or the top through the polaroid circles. Rotate the polaroid and notice that the brightness of the beam changes. You can also change the brightness of the beam by rotating the polaroid when you place it between the light source and the left end of the cylinder. This shows that the scattered light out of the tube is polarized.

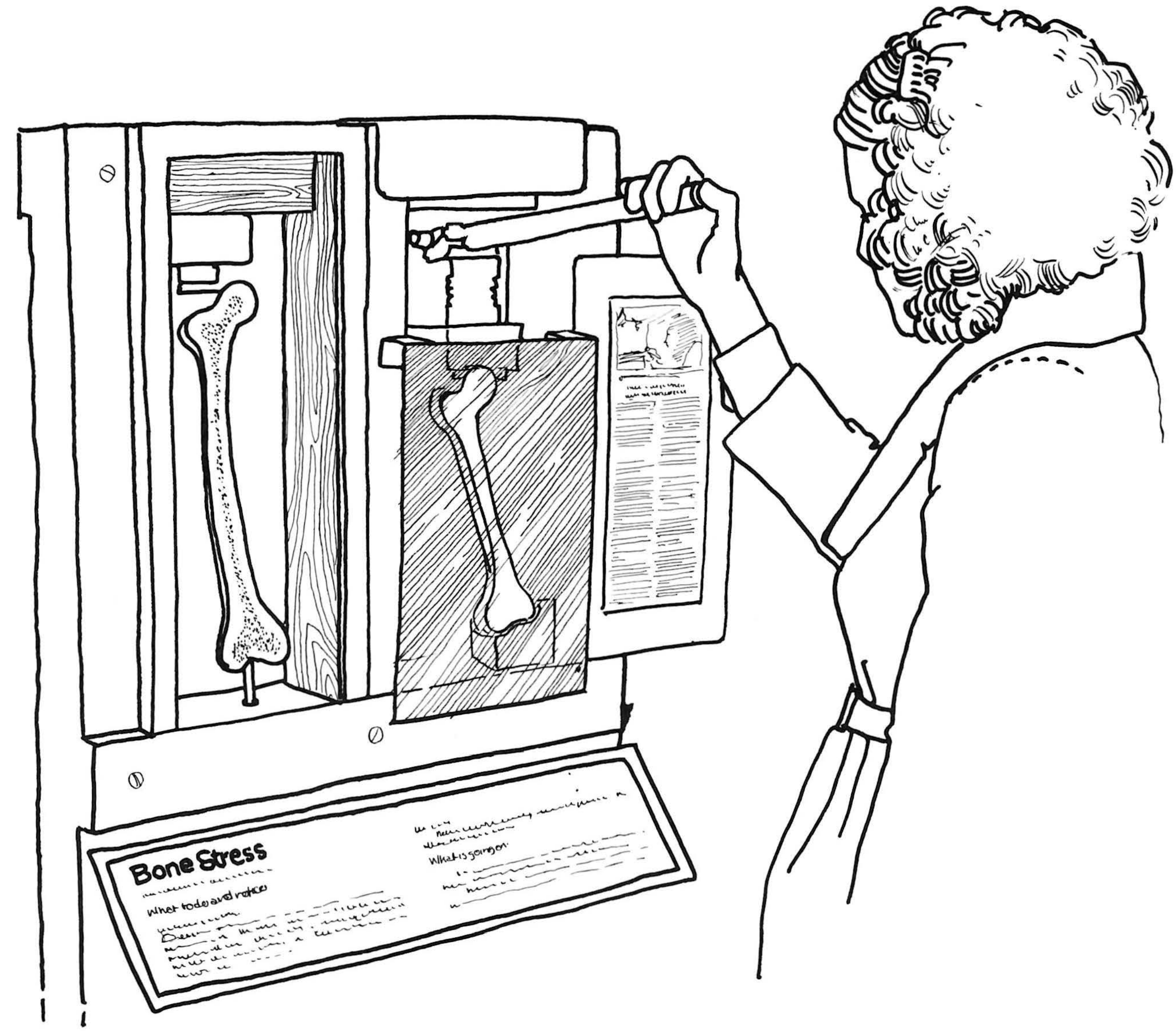
What is going on:

White Sun: Light coming from the sun is white. This white light is composed of all the colors of the spectrum, red, orange, yellow, green blue, and violet.

Blue Sky: When the white light coming from the sun hits the earth's atmosphere it collides with groups of molecules in the air and is scattered (or spread about). The more rapidly vibrating blue light in the spectrum tends to scatter more readily than the more slowly vibrating red light. As a result of this scattering of the blue waves into the atmosphere our sky appears blue.

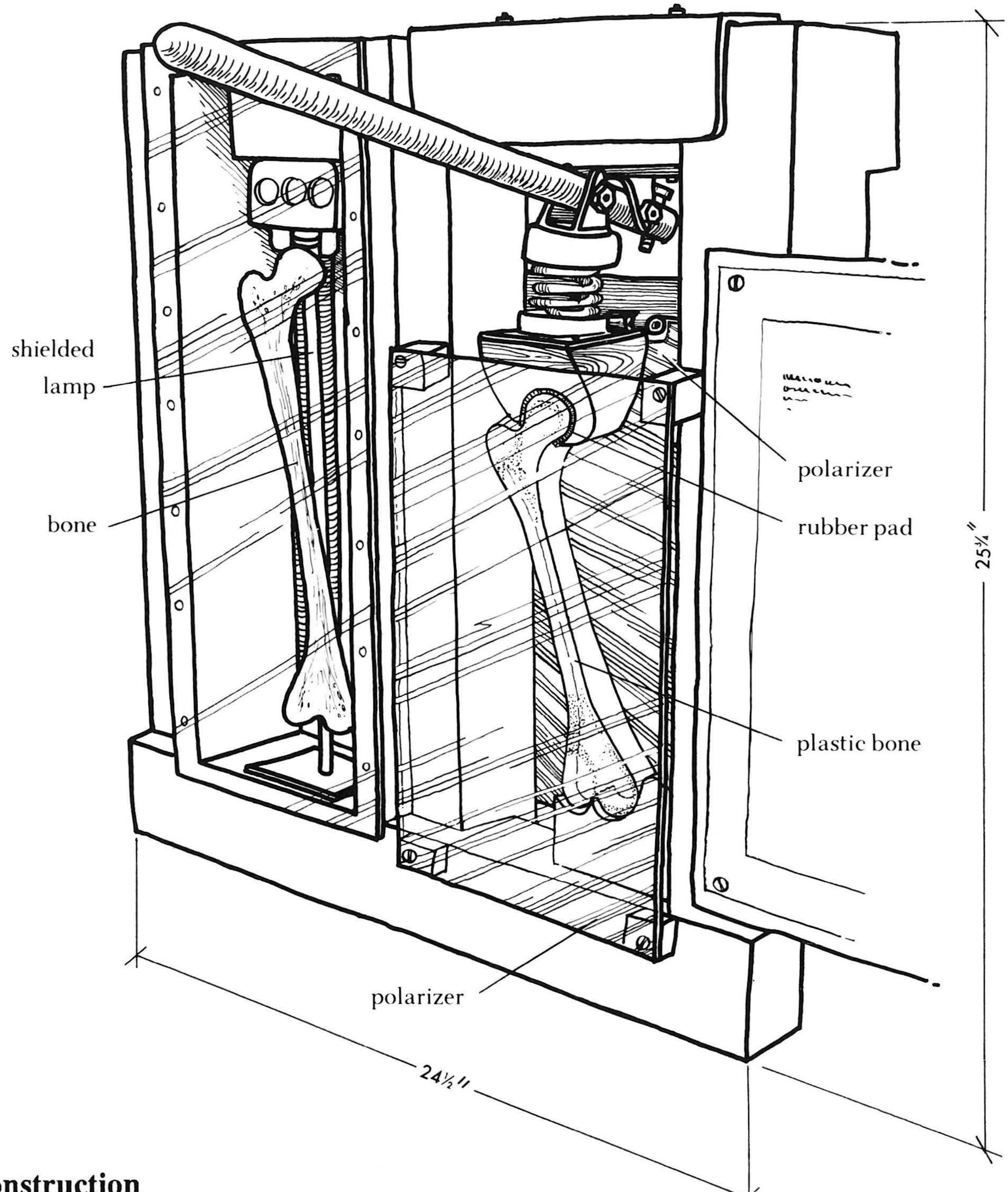
Red Sunset: When the setting sun is low on the horizon most of the blue light waves have been scattered out before they reach our eyes. These blue waves have now been scattered out of the original white light from the sun. The direct rays that do reach our eyes are therefore predominately red and orange.

Bone Stress



Description

A human thigh bone (a femur that has been cut in half along its length) is displayed next to a clear plastic model of the same bone. The plastic femur can be put under the same type of loading stress that it would experience in the body by pulling down on a lever. The stress patterns in the plastic bone are made visible because the bone is mounted in front of a light between crossed polaroid material. Stress patterns in the plastic bone can then be seen to approximate the internal strengthening structures in the real bone.

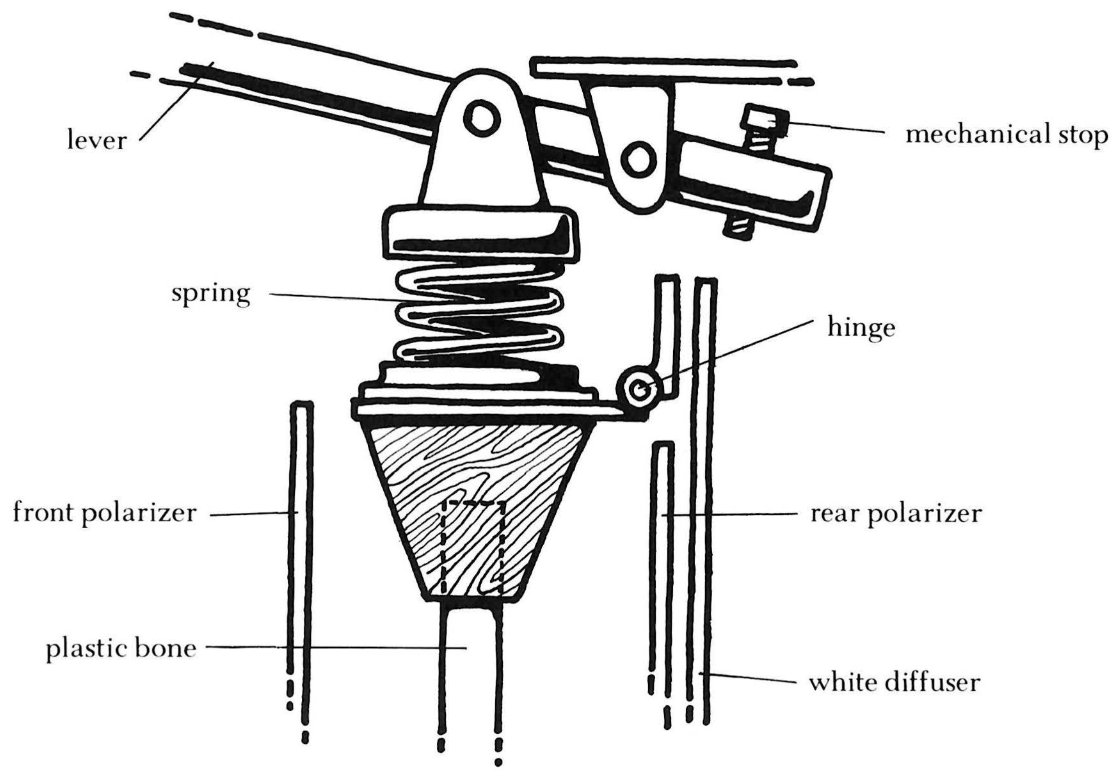


Construction

The frame of the exhibit is built of strong 4x4 pine lumber since the exhibit as well as the plastic bone is placed under moderate stress (kids hang from the lever). The real femur is mounted vertically between two pieces of plexiglas® with a shielded showcase bulb (tubular incandescent) behind it to reveal the internal structure.

Unfortunately, the source that provided us with a bisected human femur no longer stocks human bones. When we built a duplicate of this exhibit, finding a human femur proved quite difficult. We suggest you check with the following two sources, both of which occasionally have human bones in

detail of lever assembly



stock:

Carolina Biological Supply
2700 York Rd.
Burlington, NC 27215
(919) 584-0381

Maxilla and Mandible
451-5 Columbus Ave.
New York, NY 10024
(212) 724-6173

The femurs available from these sources are not bisected, and you must cut the bone yourself. It may be possible to substitute an animal bone for the human bone, but we have not experimented with animal bones to date.

The plastic bone is cut out of a 1" thick sheet of plexiglas® and annealed in the oven for 12 hours at 175 degrees Fahrenheit to increase its strength and remove stress lines due to machining. It is mounted vertically between two wooden blocks with rubber insulation. The blocks are cut on a band saw to conform to the ends of the bone and act as "sockets" as in the body. The bone is connected to the stressing lever, with lever ratio of 7:1, through a large thick spring held in place by welded steel cups on the upper block of wood and lever. The upper block is held in place with a door hinge. The lever protrudes about 15" in front of the exhibit and has a mechanical stop to prevent the plastic bone from being over stressed. As mentioned in the description above, the plastic bone is housed between two pieces of plexiglas® with crossed polaroids® mounted on their inner surfaces. Behind the rear polaroid® is mounted a light box with incandescent illumination through a white plastic diffuser.

Related Exploratorium Exhibits

OPTICAL ACTIVITY AND CIRCULAR POLARIZATION

Rotating Light
Glass Catfish (Glass Fish)
Polarized Light Mosaic

Use of polarized light to detect stress.

What to do and notice:

The Human Thigh Bone

The lines you see inside the bone grew in response to forces acting on the bone. The stress or force acting on the bones created and changes the inside structure of the bones as we grow from infant to adult or from thinner to fatter, etc. The plastic bone exhibit shows how these changes could take place.

Plastic Bone

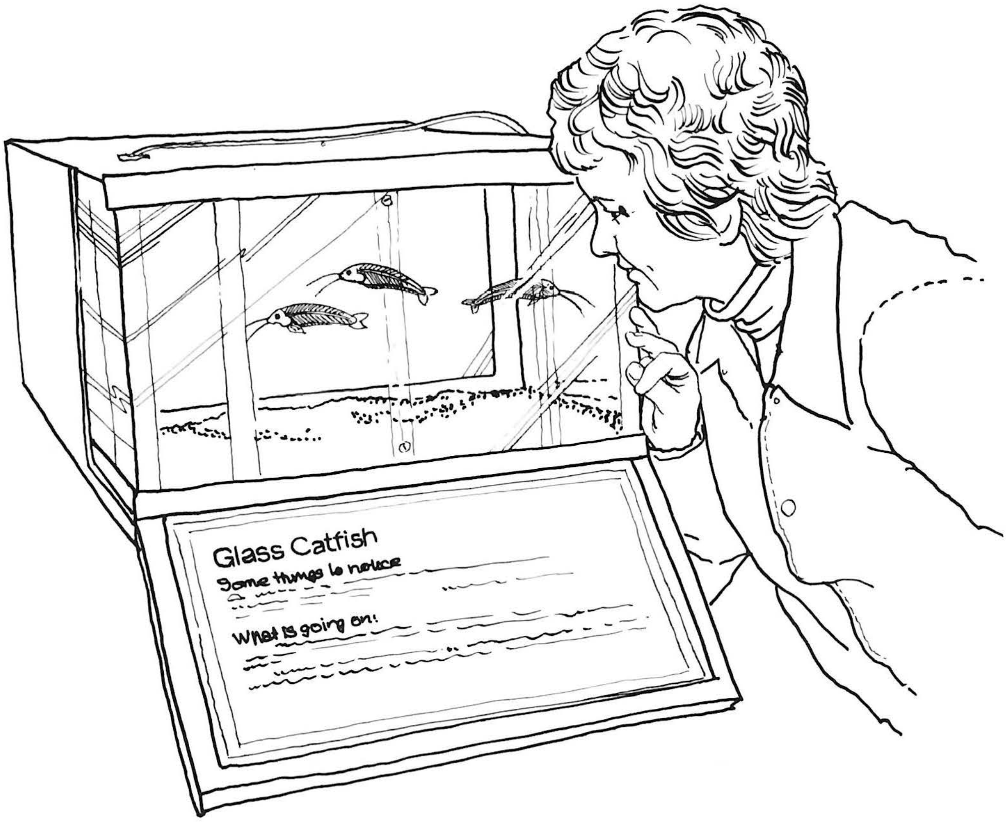
Pull the lever all the way down to squeeze the plastic bone. You will see many rainbow patterns.

What is going on:

With the use of polarized light it is possible to detect stress in an object. Many industries use this method to detect stress points.

Certain plastics under stress will twist polarized light at different angles, depending on the amount of stress. If you calculate the angles of the polarized light you could then calculate the amount of stress.

Glass Catfish (Glass Fish)



Description

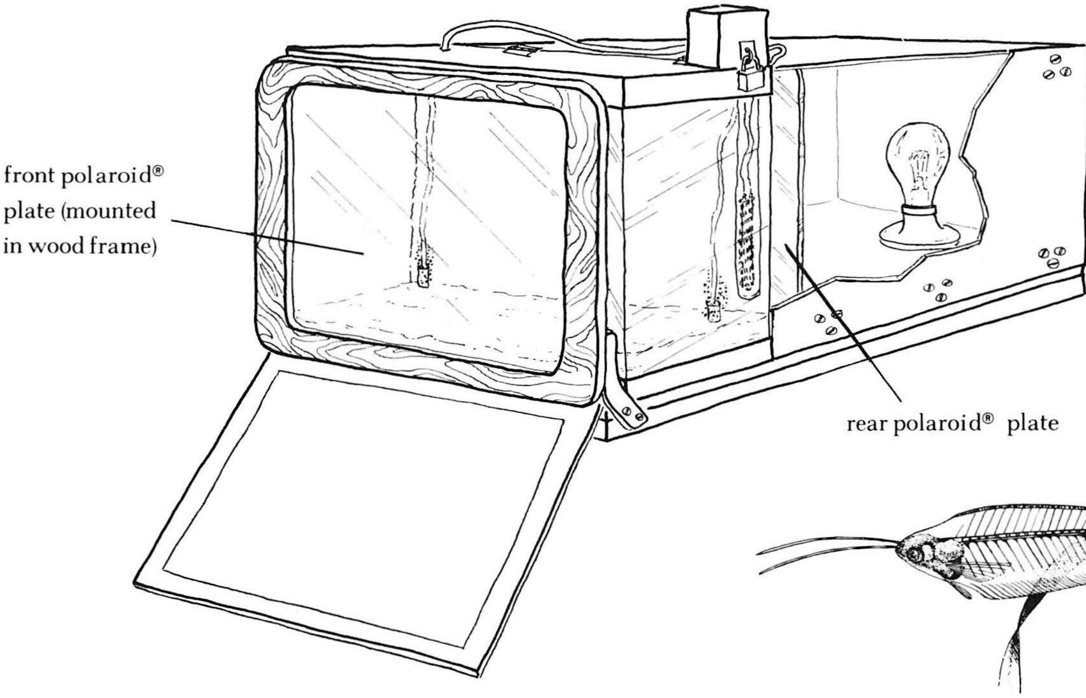
This exhibit demonstrates optical activity in a most spectacular way. The visitor looks into a fish tank and sees clear fish swimming in an apparently black tank. When observed from the side, the fish are still clear but the water they swim in looks normally clear.

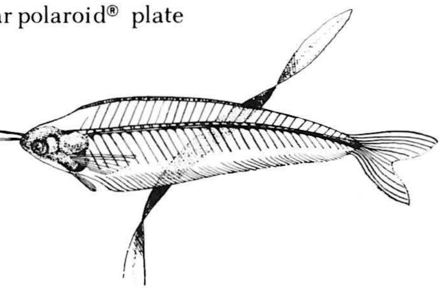
Construction

Glass Catfish is built around a 15 gallon fresh water aquarium. The tank is equipped with the typical under-gravel filters and heaters needed to support tropical fish. It is mounted on a wooden stand 48" above the floor (at about eye level) with a stool for children. Mounted in front and back, but separated from the tank are large pieces of polarizing material supported on sheets of plexiglas® (the polarizing material is on the side nearest the fish tank). The planes of polarization of the two polaroids® must be crossed (at 90 degrees to each other) so that the tank looks dark when looked through. The polarizers are not mounted on the tank itself as water spillage could damage them. The table extends behind the tank and provides space for the rear polaroid® and 200 watt clear incandescent bulb which illuminates the tank. A masonite box covers this space, cutting down on the light leaking into the surrounding area. A hinged extension of the box protrudes over the top of the tank to protect the fish from foreign matter.

The fish used are glass catfish **(Kryptopterus bicirrhes)** which are

light box (cutaway - rear of box is open)





available seasonally (best in winter and spring) from most tropical fish stores. We feed ours brine shrimp or dry tropical fish food. Care must be taken to keep the temperature of the tank very constant as the fish can not tolerate variations in temperature and will die. Our heater is set at 68 degrees and has a locked box over it to prevent unauthorized tampering. The filter tubes and heater should be located in front of the tank as the fish like to hide in shadows, defeating the purpose of the exhibit.

Additions and Changes (1990)

The name of this exhibit has changed from Glass Catfish to Glass Fish because we also use the Indian glass fish (*Chanda ranga*) as well as the glass catfish. These fish are also called Painted Catfish, because they are actually hand-painted in Thailand. (The paint wears off over several months.)

Originally, the lid to our tank was made of masonite, but the water warped the lid. We replaced the lid with one made of laminated formica, which seems to work fine. A glass or plastic lid might also work.

Related Exploratorium Exhibits

OPTICAL ACTIVITY

Bone Stress
Polarized Light Mosaic
Rotating Light
Two Wheels and a Ball

Exploratorium Exhibit Graphics

Some things to notice:

If you look at the fish through the end of their tank environment, you will notice that the fish blend in their environment. However, you will still see some color. The color is due to the fact that the ribs of the fish are acting as a diffraction grating and not due to the polarization effect.

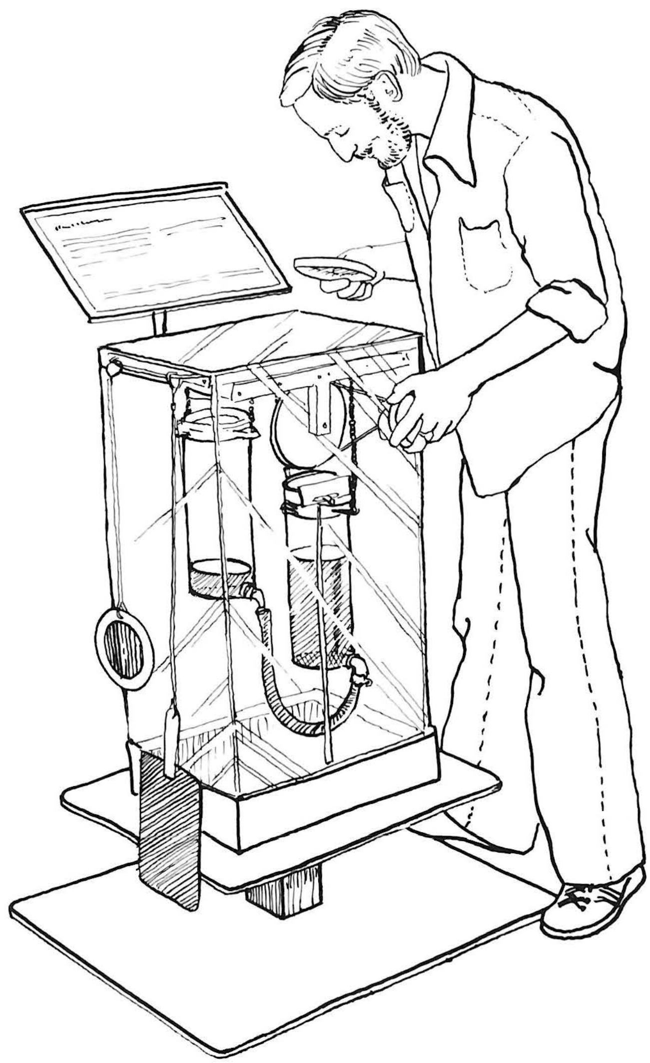
What is going on:

There is a sheet of polaroid on the back of the fish tank and one on the front. They are arranged so that the front sheet cuts out most of the light that the back sheet of polaroid lets through, leaving a dark field.

The direction of vibrations of the polarized light which comes from the back of the tank is twisted as it passes through the fish. This twisting is caused by the structure of the molecules within the cells of the glass fish. The fish are said to be optically active. (see exhibit "Twisting LIght")

This twisted light is not cut out by the polarizing material on the front of the tank, therefore the fish look bright against the dark field.

Rotating Light



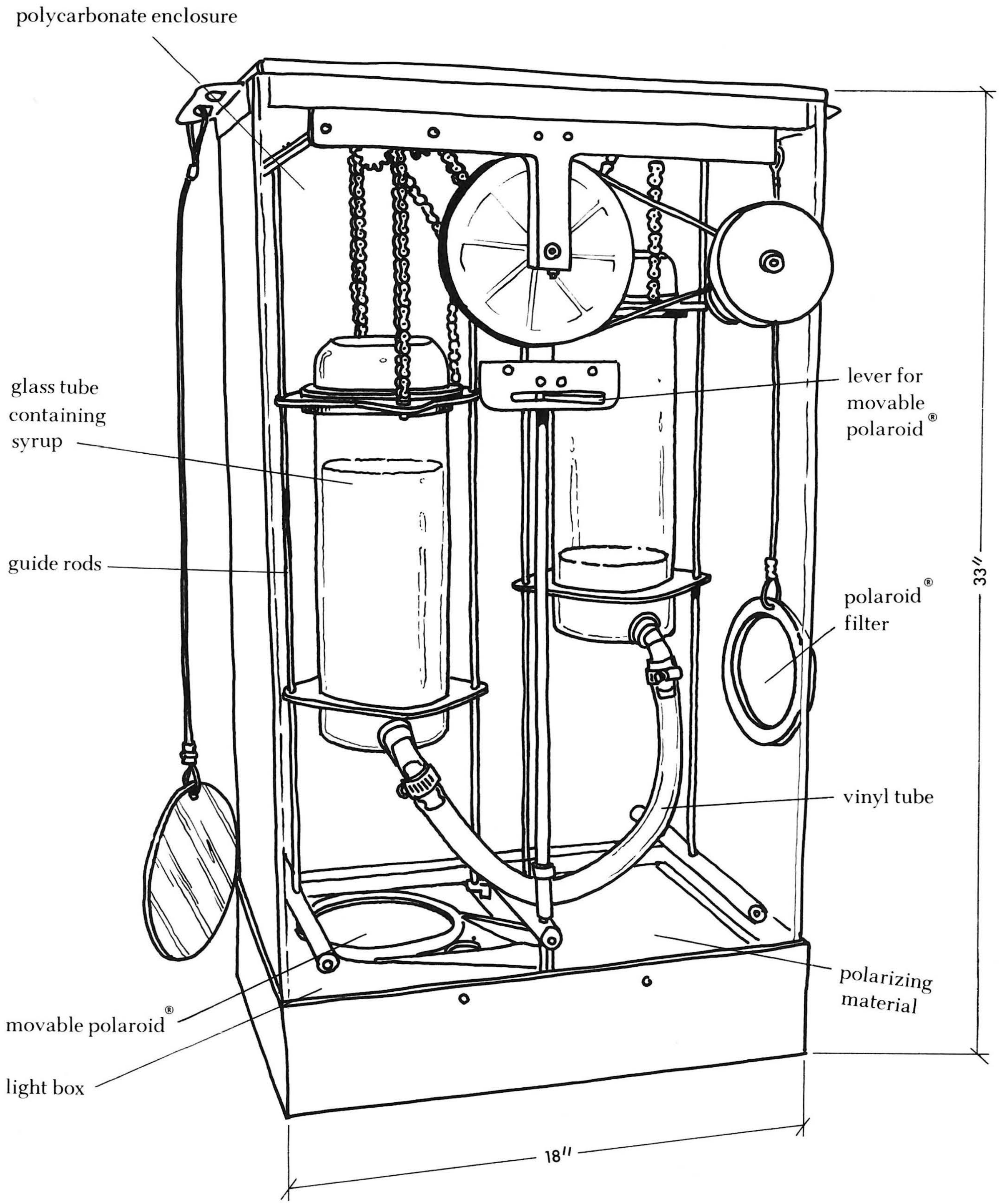
Description

The visitor, looking through a polaroid® filter, stares down into a cylinder of syrup with another piece of polaroid beneath it. As the level of the syrup is changed with a knob in front of the exhibit, various colors can be observed. Only by rotating the hand held polaroid® can the visitor see the same color as the level is changing thus demonstrating that the plane of polarization is rotated by the syrup.

Construction

Rotating Light is a complicated exhibit and can be executed in a much simpler way. For this reason it will only be briefly described.

Two glass tubes 4" in diameter and 12" long, hold a solution of Karo syrup, water (to make the solution thinner), and preservative (Zephiran Chloride 17% solution diluted as directed). Karo syrup is optically active and almost clear making it ideally suited.


polycarbonate enclosure
glass tube containing syrup
guide rods
movable polaroid®
light box
lever for movable polaroid®
polaroid® filter
vinyl tube
polarizing material
33″
18″

The two tubes are connected to each other by a length of vinyl tubing attached to drain spouts at the bottom of each tube. A knob on the outside of the polycarbonate enclosure allows the user to raise one tube while lowering the other, changing the level of syrup in each. The tubes are raised and lowered through a chain drive assembly guided by stainless steel rods (see diagram). The visitor looks down through the 3/8" glass top of the exhibit through 6" diameter polarizers hung on the exhibit with steel cable. The tubes are lit from beneath with fluorescent lamps under a white diffuser. The light is polarized with 2 pieces of polaroid® material, one for each tube, sitting on top of this light box. One of these polarizers moves by means of a spring loaded lever sticking through the front of the exhibit enclosure. A red filter hangs from the exhibit, as well as a small mirror for use by people confined to wheelchairs.

Critique and Speculation

The water in the solution slowly evaporates leaving the remaining syrup too thick for satisfactory operation of the exhibit. This is rectified by mixing a new solution or replenishing the old one (heating with an immersion heater to thin the solution while adding hot sterilized water). Either way, this is a messy proposition.

Related Exploratorium Exhibits

POLARIZATION

Polarized Light Mosaic
Bone Stress
Glass Fish
Two Wheels and a Ball

Exploratorium Exhibit Graphics

To do and notice:

This exhibit illustrates the changes in polarized light as the light passes through a container of sugar solution. The light is polarized by polarizing filters beneath each of the glass containers.

Look down without a polarizing filter into one of the containers of sugar solution. The solution appears colorless.

Look through a polarizing filter into the container. Notice that the solution has color and that the color changes as you rotate the polarizing filter.

Hold the polarizing filter in one position (or set it on the table top) and turn the crank to change the depth of the sugar solution. Notice that the color changes as the depth of the solution is changed.

Raise one of the containers until it is empty.

Look through a combination of red and polarizing filters.

Rotate the polarizing filter until all the red light is blocked and the cylinder looks black.

Slowly turn the crank and fill the cylinder with sugar solution.

Notice that you can keep the solution black by slowly rotating the polarizing filter as the solution rises in the cylinder.

How high does the liquid have to rise before the polarization has rotated by 90 degrees?

Look for colored reflections as the containers fill and empty. Also look at the colors obtained by looking through a polarizing filter at the plastic side walls of the box. The top of the box is glass.

What is going on:

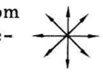
When polarized light passes through some substances (like the sugar solution in this exhibit), the direction of its polarization is changed. It is rotated to one side or the other.

The amount of rotation depends on the amount of sugar the light passes through (more sugar produces more rotation) and on the wave length (color) of the light. Blue light with its shorter wave length is rotated more than red light which has a longer wave length. When the white light emerges from the solution, each color in the white light has its own different direction of polarization. However, since our eyes alone cannot detect the direction of polarization of the light, the light appears colorless when viewed without a polarizing filter.

When the polarizing filter is used, the light with polarization parallel to the axis of the filter comes through the filter. The intensity of other colors in the light, which have different polarizations, is diminished. If a certain color light has its polarization perpendicular to the axis of the polarizing filter, it is blocked out completely.

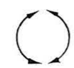
How the light is rotated:

The light emerging from the light source at the bottom of the exhibit is unpolarized. It vibrates in all directions:



The lower polarizing filter under the sugar solution converts this light to plane polarized light, which vibrates back and forth in one direction only:

This back and forth motion is the combination of two opposite circular motions:

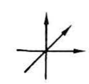


In the sugar solution the light vibrating with a clockwise circular motion travels faster than the light vibrating with a counterclockwise motion. The latter light is delayed with respect to the former:

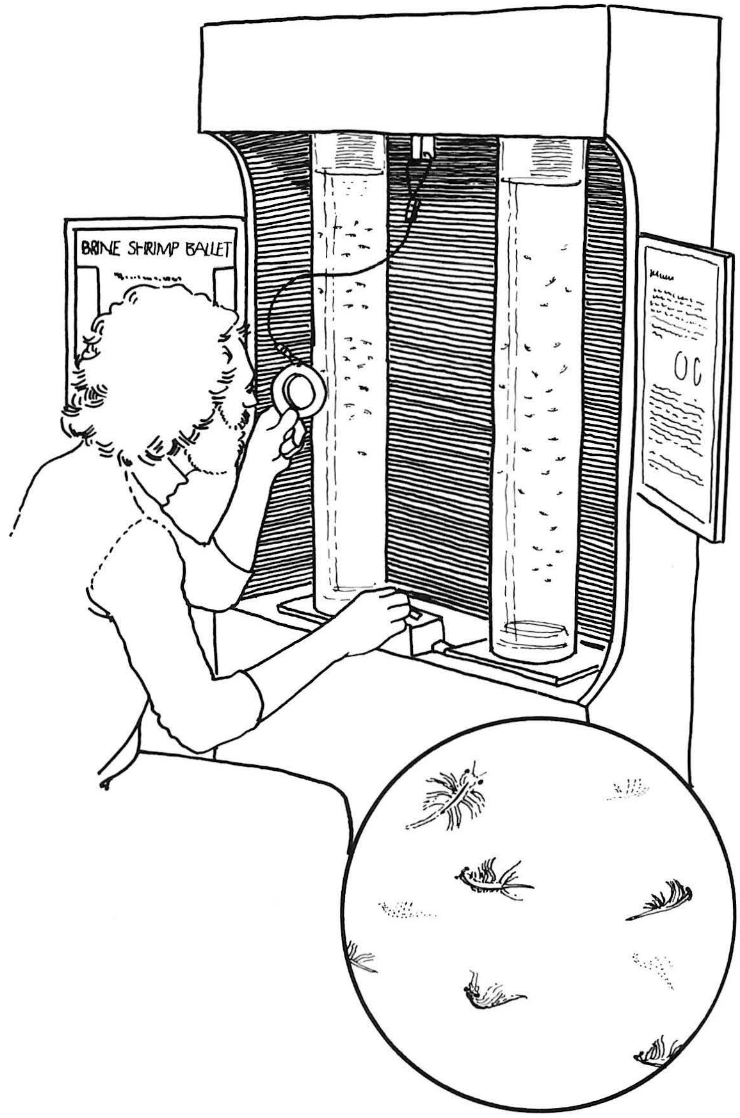
When the light emerges from the sugar solution the two circular motions combine to make a straight line motion that is vibrating back and forth in a different direction from the light entering the solution:

As the light travels through the solution it always remains plane polarized light, but the direction of polarization changes.

The above description is for monochromatic (one color) light. When white light goes through the sugar solution, each color emerges with its own direction of polarization:



Brine Shrimp Ballet

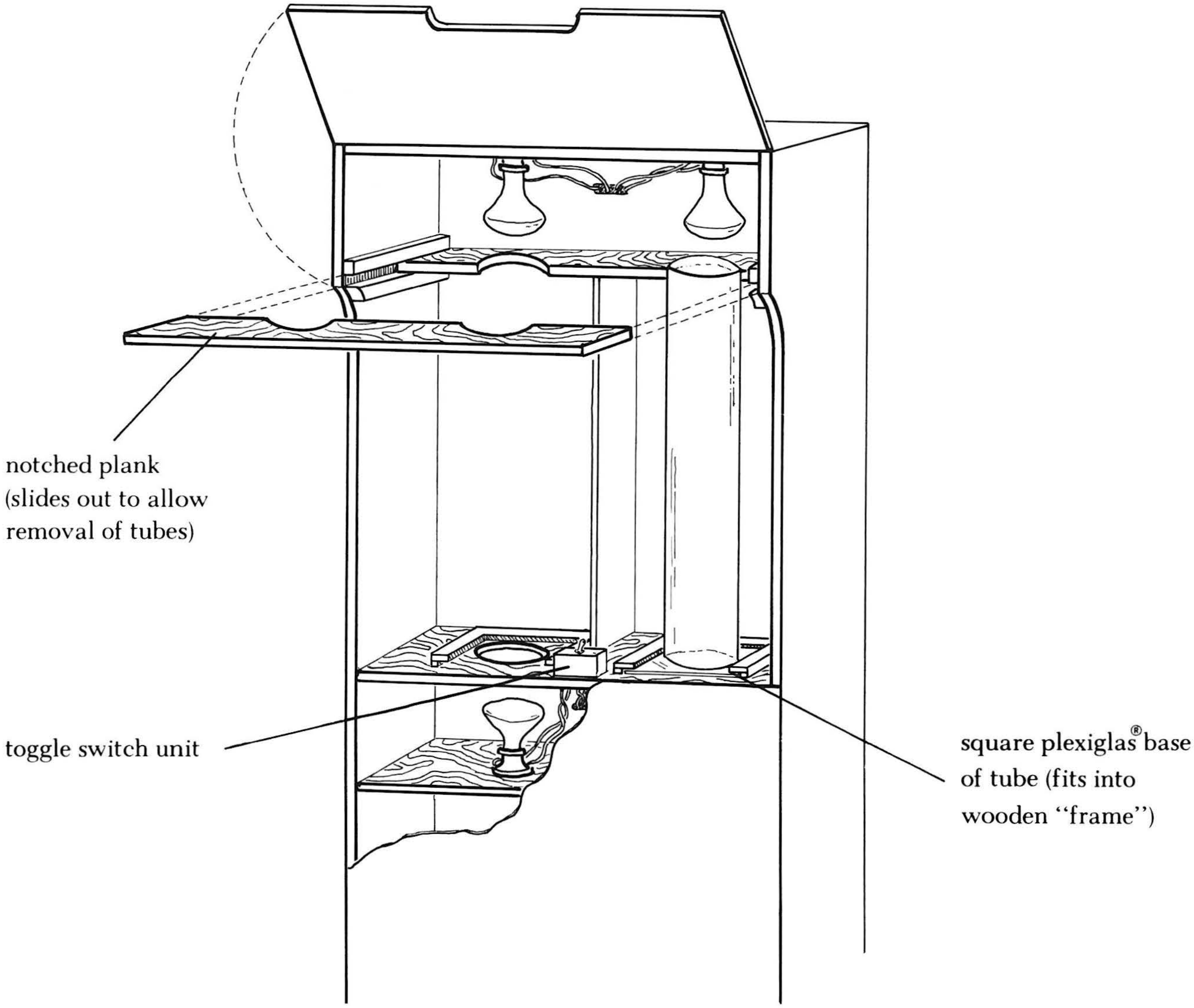


Description

Brine shrimp may be tested to see how they react to light coming from either above or below their tank. Brine shrimp show a phototaxis (response to light) which has never been completely understood. The adults swim away from light, and the larval forms swim towards it. The shrimp always orient themselves so that their ventral surface faces the light.

Construction

The brine shrimp are kept in clear acrylic tubes 30" tall and 5" in diameter. Two tubes are displayed (one is illuminated from above, the other from below) so that the behavior of the shrimp can be observed under both lighting conditions simultaneously. A switch on the front of the exhibit will alternate the lighting on the tubes. The lamps are 30 watt incandescent spot-



lamps. A magnifying glass is provided to allow visitors to look at the brine shrimp more closely. The background behind the tubes is painted black for maximum contrast in viewing the shrimp. About one teaspoon of brine shrimp are needed in each tube. The shrimp will last about 24 hours and will last longer if air is bubbled through the tube.

Critique and Speculation

The photo-negative and photo-positive behavior of the adult brine shrimp are subject to seasonal variations. We continuously sample the shrimp population of the San Francisco Bay. Their reactions may vary according to such factors as oxygen content and temperature of the water.

Additions and Changes (1990)

Originally, the acrylic tubes in this exhibit were glued to square plexiglass bases that slid into a square wooden frame, as shown in the diagram. We found that leaks tended to develop between the tube and the plexiglass base. To prevent this problem, we replaced the square bases with internal plexiglass plugs, glued inside the tubes. The wooden frames that held the square bases were replaced with circular frames

that just hold the tubes in place. The notched plank shown at the top of the exhibit no longer has to slide out: each tube is simply inserted into the hole in the plank at an angle and lifted into the circular frame.

We have also sandwiched the magnifying glass between two masonite doughnuts, so that the glass won't scratch the acrylic tube. The magnifying glass is attached to a cable with a swivel, and the cable is attached to the exhibit. The swivel lets the magnifying glass rotate freely without twisting the cable. This extends the life of the cable considerably.

In addition, we recommend that you change the water in the tube at least every 24 hours.

Related Exploratorium Exhibits

PERCEPTION OF SPATIAL ORIENTATION
Plant Geotropism

PHOTOTROPISM
Pupil

Exploratorium Exhibit Graphics

What to do and notice:

Watch the brine shrimp for awhile then flick the switch between the tubes.

Notice that the direction from which the light is coming has reversed in each tube, and that the shrimp quickly begin to swim away from the light.

Look more closely by using the lens, or follow one shrimp with your eyes. Notice that when the shrimp changes its swimming direction it also flips itself over so that its ventral side (underside) is toward the light.

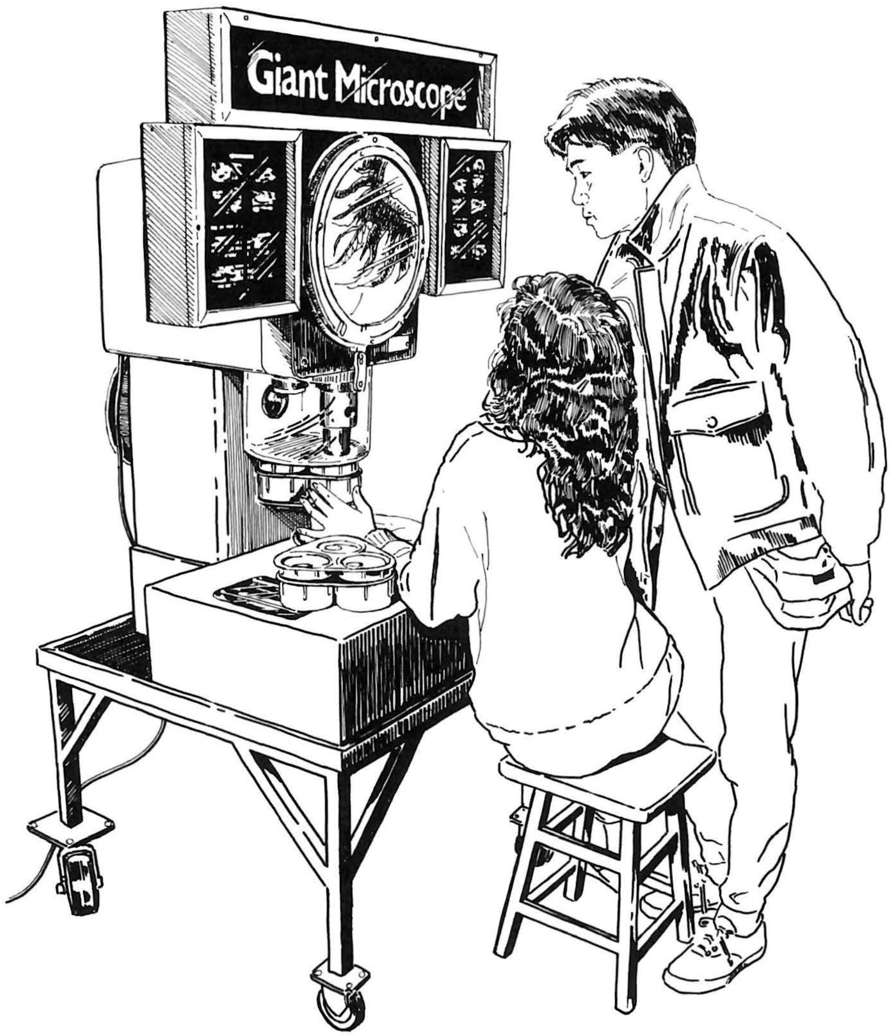
What is going on:

Adult brine shrimp are photonegative, in other words, they swim away from the light. Baby brine shrimp are photopositive and swim toward the light. This phenomena is not completely understood, but one theory suggests that the light acts to separate the adults from the babies as the adults tend to eat their children. (There are usually only adult brine shrimp in the tubes.)

Animals orient themselves in space according to information they receive from their surroundings. Many animals are sensitive to gravity while other animals orient by light. To an animal in the water the light source usually comes from above. The brine shrimp orients itself to the light by turning over on its back, ventral side up. To us the brine shrimp swim upside down, however this is the way brine shrimp naturally position themselves in space.

If you flick the switch quickly from side to side the shrimp seem as if they are dancing to the rhythm of the light.

Giant Microscope

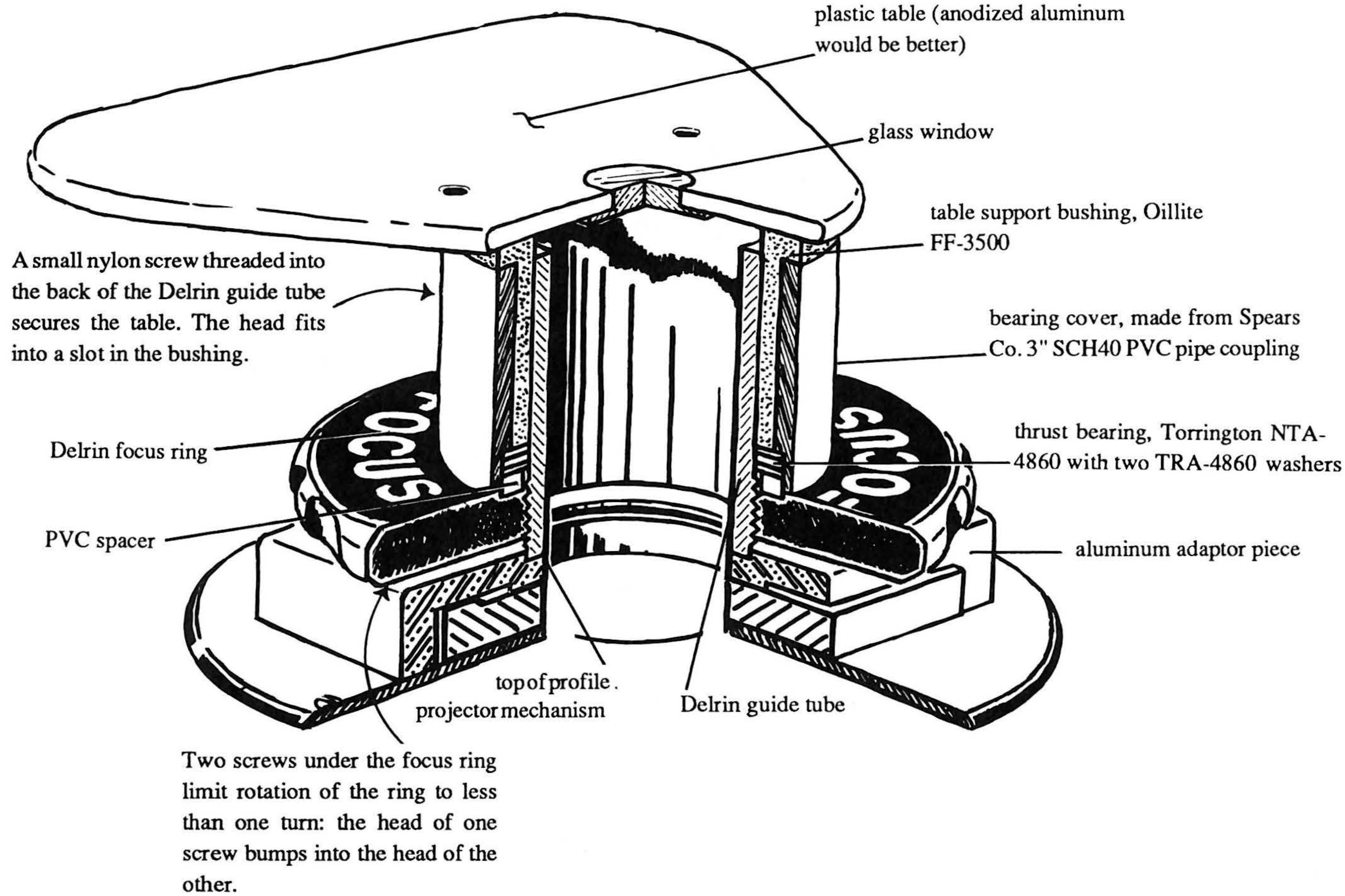


Description

A group of visitors can view protozoa, algae, and small multicellular organisms, magnified one hundred times on a 12" screen. The swimming organisms can be followed laterally by sliding the specimen dish and followed vertically by turning the FOCUS ring. On the side of the exhibit is a small fluorescent tube in a black background. When the dishes are placed over the background, the specimens are lit from the side and can be seen with the unaided eye. Even protozoa such as paramecia can be seen swimming about in this way.

Construction

This exhibit uses a Nikon V-12 profile projector as the microscope. Light from the bulb in the base passes through the condensing system, the specimen, and the objective lens, which focuses it on the rear projection screen. A mirror reflects the light from the bulb up through the specimen. In an attempt to minimize the heat on the specimens, we replaced this mirror with a mirror that does not reflect infrared. Despite this precaution, the specimens still get hotter than is healthy for some.



We also replaced the ground glass projection screen (which was marked with a black cross) with a plastic screen that had a wider viewing angle. The plastic rear projection screen is available from:

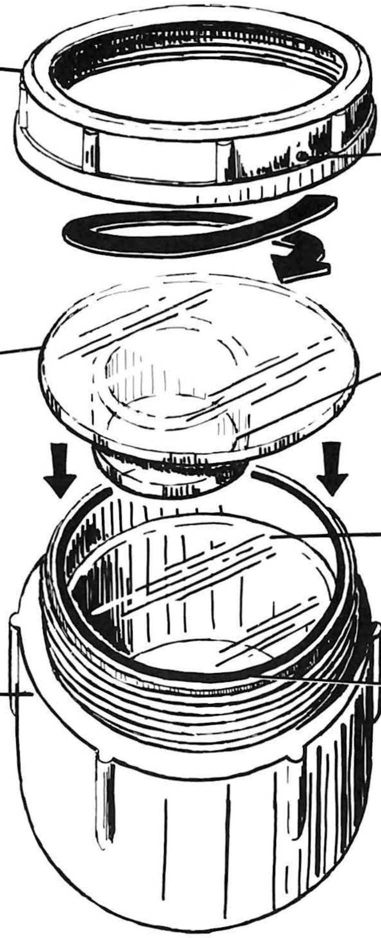
DA-LITE Screen Company, Inc.
Polacoat Division
P.O. Box 41208
11500 Williamson Rd.
Cincinnati, OH 45241
(513) 489-3222

We added an acrylic lens shield with a flat glass window set in the optical path so that the image is not distorted by the acrylic. The optically flat glass for the window (Part #D30,773) and the infrared transmitting mirror (Part #D42,414) are both available from:

Edmund Scientific Co.
101 E. Gloucester Pike
Barrington, NJ 08007-1380
(609) 573-6259

The original mechanism for focusing included parts that would inevitably wear out and would be costly to replace. We constructed our own custom-made focusing mechanism (pictured here). Like the original mechanism, ours moves the stage vertically. We screwed the new mechanism on top of the original, which we left in its lowest position.

We made our own specimen dishes, using 3" PVC conduit parts and acrylic. The specimen dishes are designed to have the volume of a culture dish. An acrylic tube glued to the clear acrylic top creates a thin viewing area, which has a depth similar to that of a wet mount preparation. The volume allows the specimens to live for a few days or more, depending on the



organism. The thin viewing area restricts the vertical motion of the specimens so that they are easier to follow with the FOCUS ring. The thin viewing area also reduces the possibility that matter will get between the specimen and the lens. The depth of the viewing area can be made to suit the specimen by cutting the acrylic tube to the proper length. If the dishes are well-populated, there will always be some specimens swimming in the viewing area.

The specimens are the most important ingredient in this exhibit. They can, with a little practice, be cultured in the finger bowls or culture dishes in the lab. Start cultures by collecting from local sources or by ordering from biological supply houses. Information on culturing can also be obtained from the supply houses. It is very helpful to have a stereo microscope to examine the progress of the cultures. Use transmitted oblique light for a good view through the thick finger bowls.

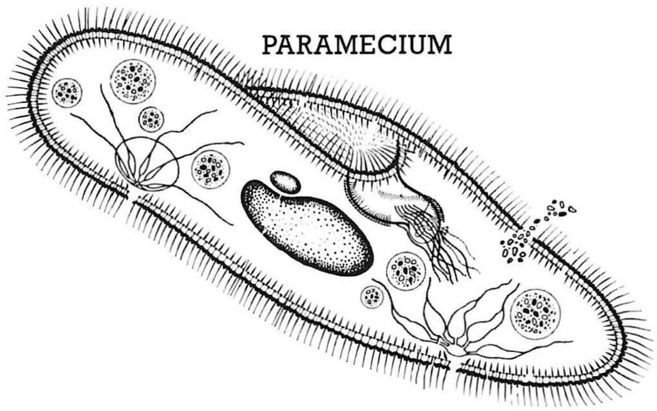
Critique and Speculation

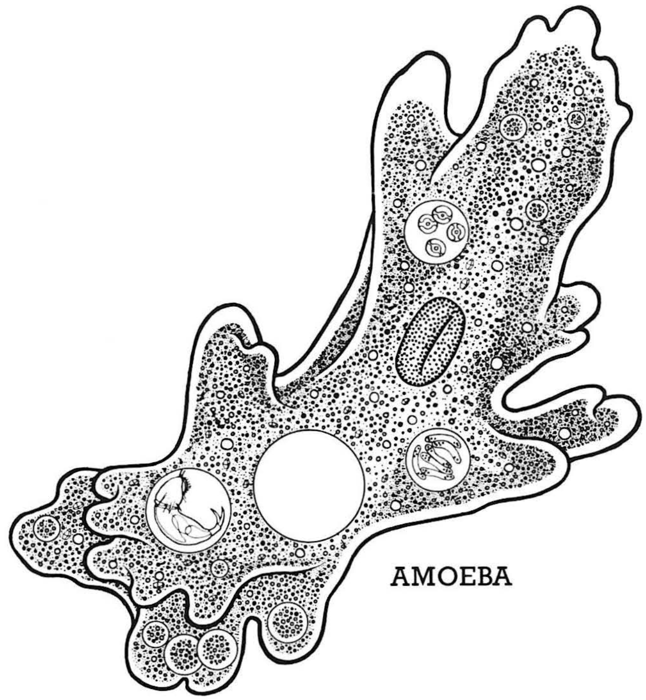
Using a profile projector, at least a new one, is not necessarily a cost effective way to make a Giant Microscope exhibit. In 1984, the Nikon V-12 and lens cost around $6,000, and in our exhibit, we do not use many of its expensive features. The light source illuminates an area much larger than the field of view, thereby causing glare and contributing to the overheating of specimens. An exhibit could be designed that incorporates the features that we added to the Nikon V-12 and leaves out the features we did not use.

Related Exploratorium Exhibits

Brine Shrimp Ballet

Marine Life





To do and notice

Notice the tray holding three containers. Put the tray on the plate under the microscope, and move it around until one of the containers is directly under the bright light. Look at the round screen in front of you to see a magnified image of the creatures in the container.

Most of the creatures you see at this exhibit are single-celled organisms.

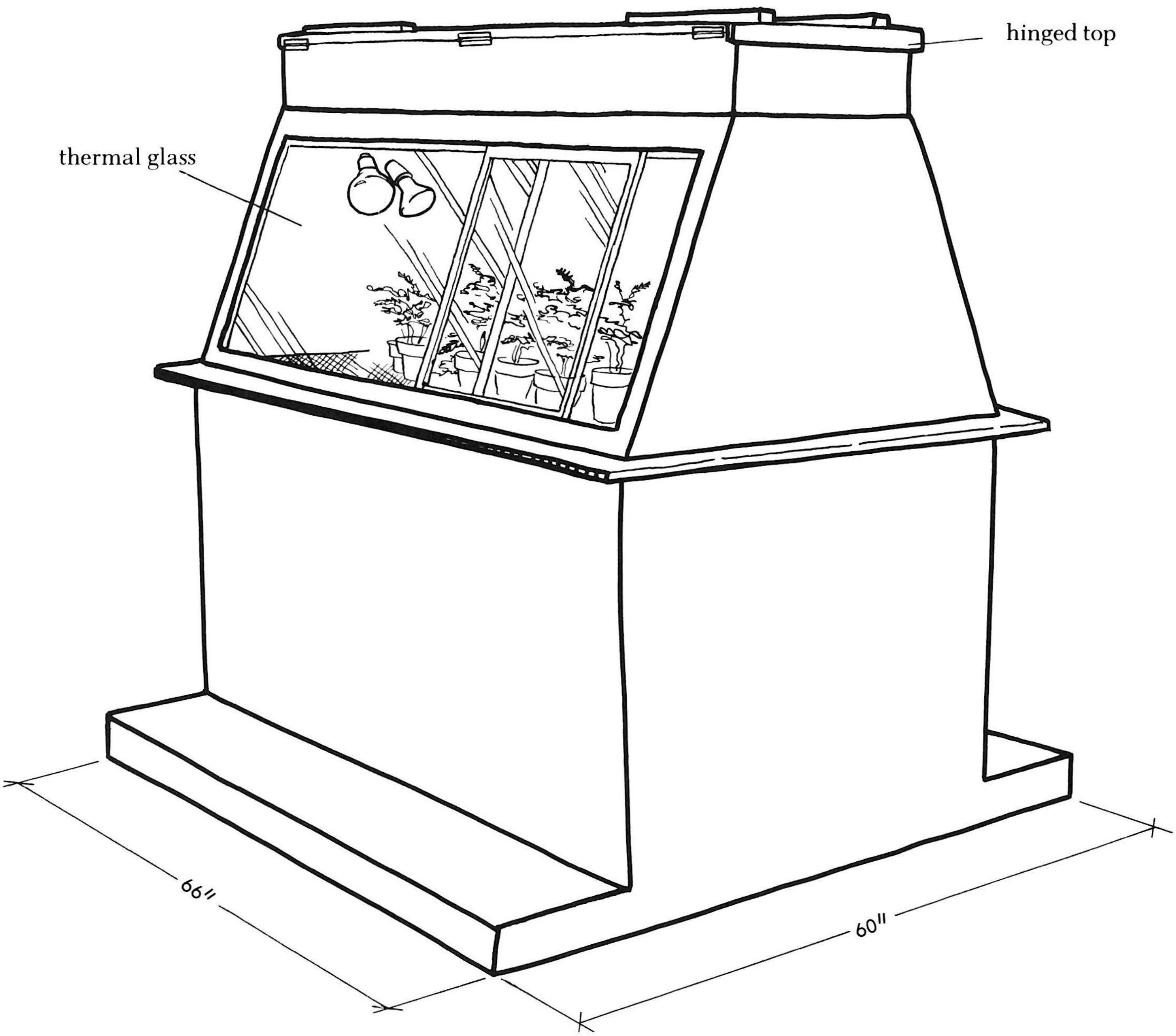
Mimosa

Description

A small greenhouse contains mimosa plants for the visitors to touch and experiment with. The mimosa is often called "the sensitive plant" because its leaves fold up when touched lightly. The house provides the proper temperature and humidity environment for the plants to prosper.

Construction

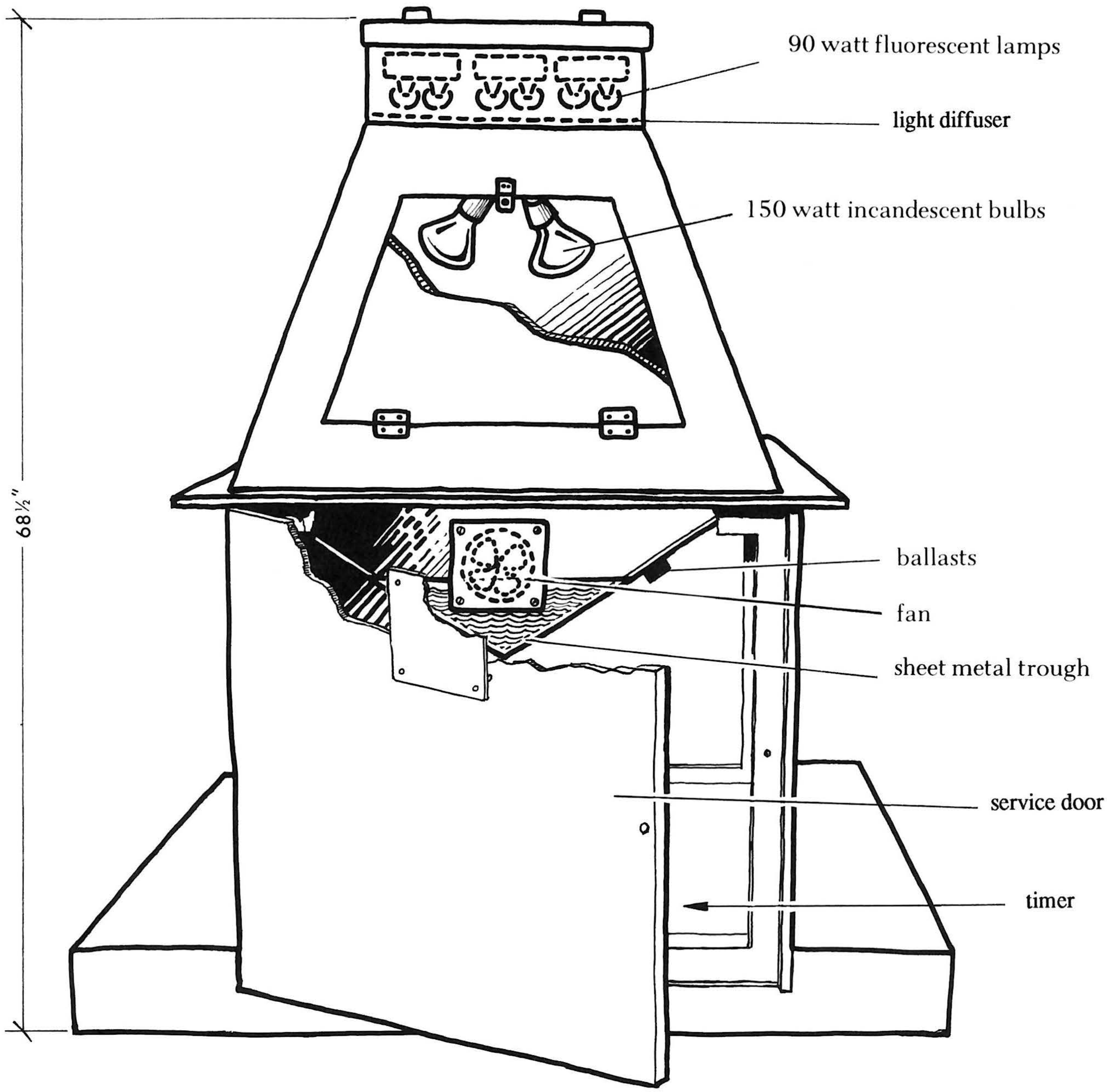
The greenhouse is a complete environment. The temperature is kept at approximately 80° F by four 150 watt incandescent lamps which, along with 6 General Electric F48PG17 96 watt fluorescent lamps, also provide the proper illumination for the plants. These lamps are turned on at 6 A.M. and off at 10 P.M. with a timer to simulate a day-night cycle. The upper half of the exhibit is enclosed with double layer thermal insulating glass. One of these windows slides to the side to provide access to the plants. The plants sit, each in its own pot, on a wire screen. Below the screen is a trough made of galvanized sheet metal folded and lead soldered into shape, which contains water to keep the greenhouse at a humidity of approximately 40% or above. The fluorescent lamp ballasts are attached to the trough which acts as a heat sink and has the added benefit of heating the water in it to increase the humidity. The trough also catches the extra water after watering the plants. A fan blows air across the water to provide circulation and another fan, mount-



ed in the top of the exhibit with the lamps, exhausts hot air generated by the lamps.

The plants **(Mimosa puduca)** are grown from seeds which can be easily purchased. The seeds are prepared by removing the husk-like outer covering from the seed and planting about 1" deep in very hard-packed soil. The plants are watered so the soil is always moist.

We've noticed that the plants are not sensitive just after they are watered or pruned. A plant will grow tall and scrawny if the terminal buds are not clipped to make it bushy. It is important not to let the plants flower or they will die. We have numbered the pots to keep track of the plants and rotate the ones the public handles since they take quite a beating.



Additions and Changes (1990)

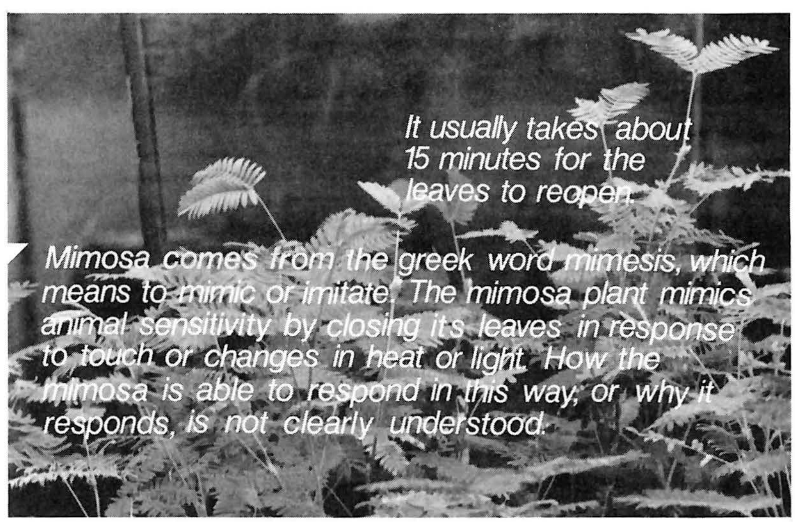
Contrary to our guidelines, this exhibit is nearly impossible to move. If you build this exhibit, we suggest you redesign the base so that it can be lifted by a forklift.

To keep your plants healthy, you need to change the lamps every six months, or whenever the leaves begin to yellow. Our exhibit includes a service door at the bottom of the exhibit on one end where we store the spare bulbs. The timer for the lights is also located in the bottom of the exhibit.

Related Exploratorium Exhibits

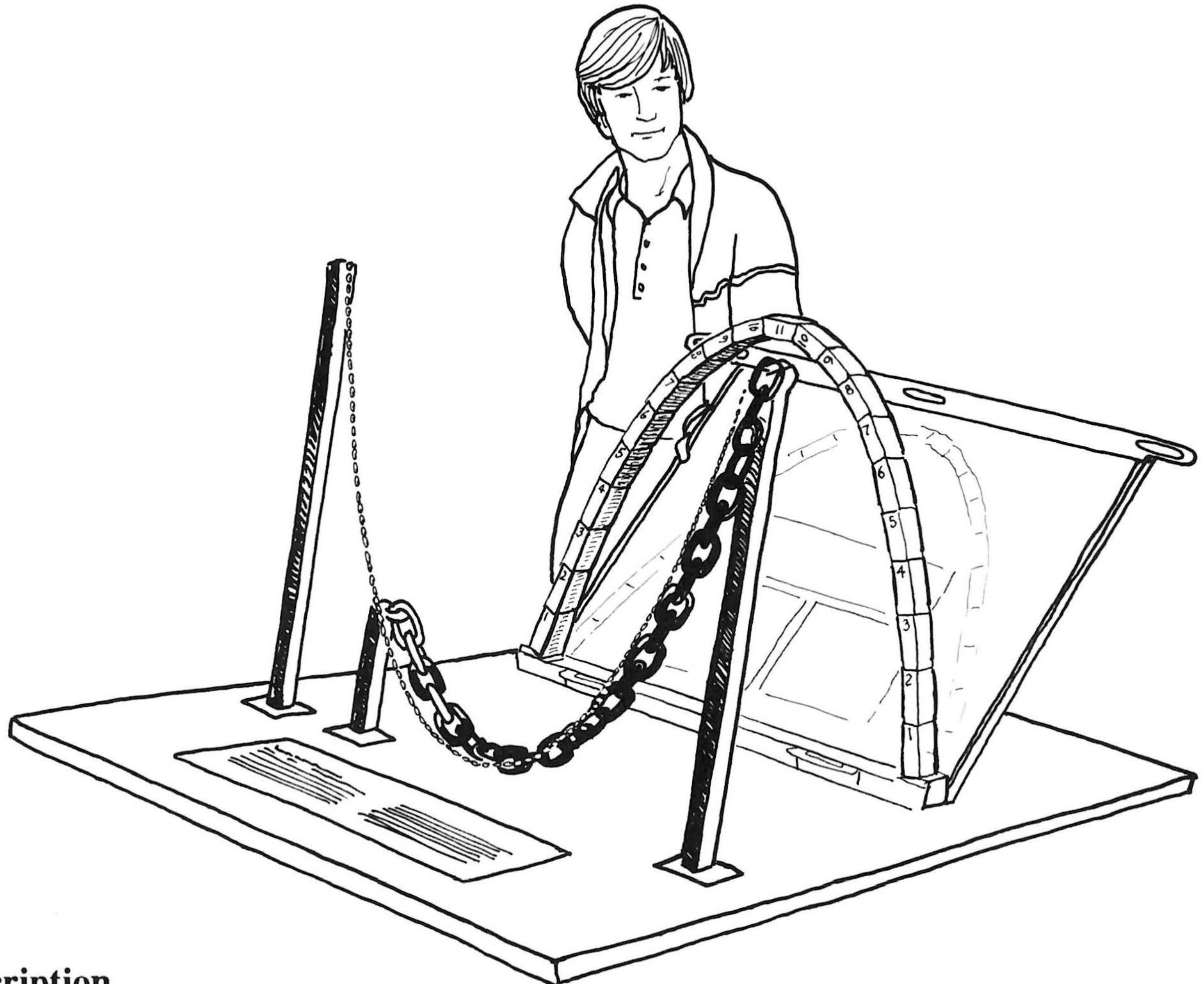
Language of Nerve Cells
Plant Geotropism

Exploratorium Exhibit Graphics



Photos Susan Schwartzenberg

Catenary Arch



Description

Visitors build a free-standing arch of numbered blocks by laying the blocks on an outline drawn on a horizontal board and then tilting the board up to a vertical position. The board can then be tilted back down, leaving the arch standing on its base. The curve of the arch is called a catenary.

When you hold a chain by its ends, the chain assumes a catenary curve, the same shape as the arch except upside-down. On the table of the exhibit, there are two chains suspended from posts, a heavy chain and a light chain. Both chains form curves that match the curve of the arch.

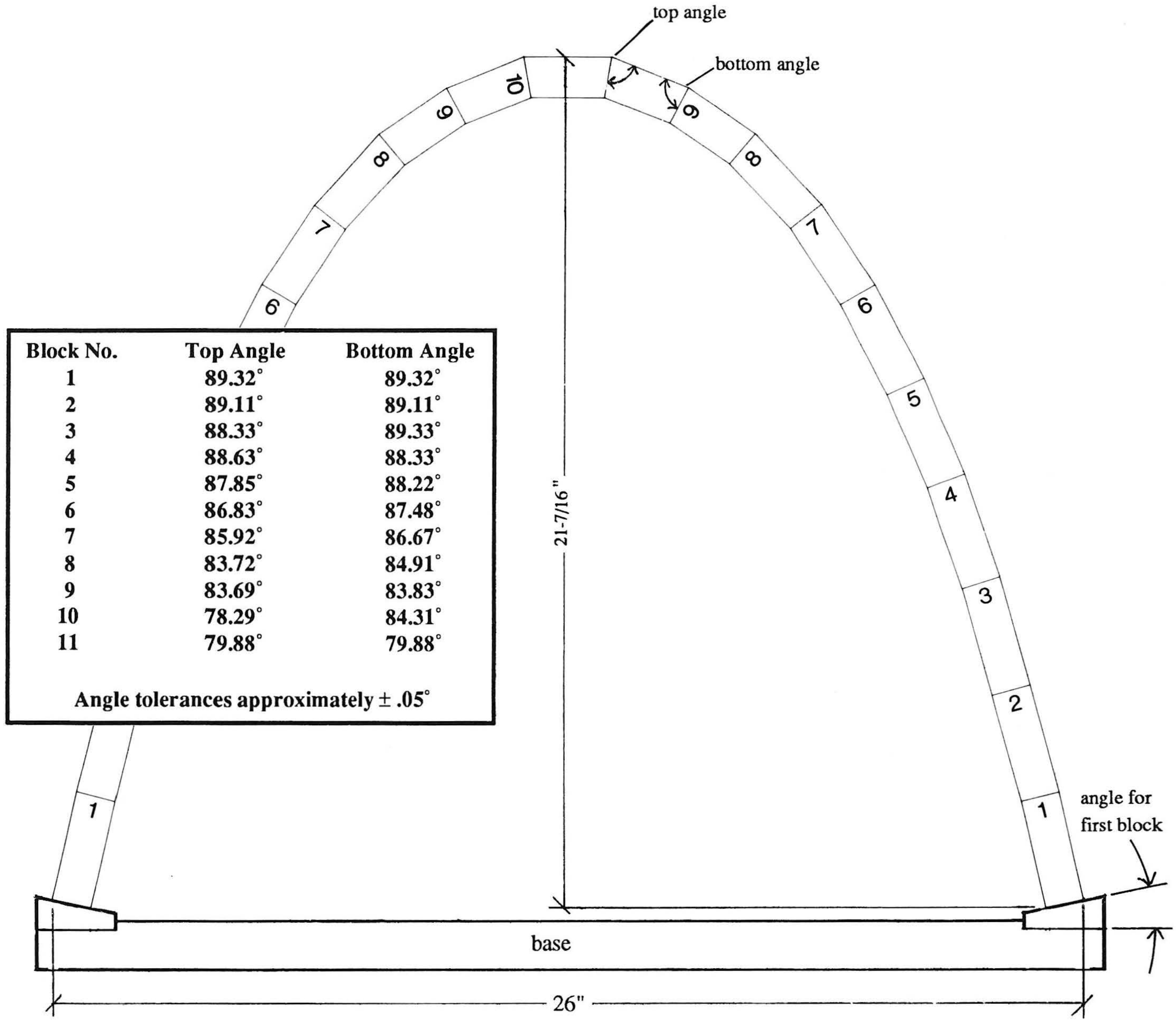
The arch of smooth blocks and the length of suspended chain are stable for similar reasons. Neither the chain links nor the block surfaces can withstand shear or sideways forces; they can only withstand forces that are along or parallel to the line of blocks or the length of the chain. The chain can withstand tension only and the blocks can withstand compression only.

Construction

The equation for a catenary is:

$$y(x) = a(\text{Cosh}\ (x/a)\text{-}1)$$

The value of a in our version is 5.6 with x and y in inches. Using a plot of the above curve as a centerline, we drew an outline of the arch. We used this outline for the layout board of the exhibit. We chose a block thickness of 1". The combination of this curve and this block thickness gives us an arch that stands 21.4" high and measures 24" across the base, measuring from the inside edge of the blocks.



Block No.	Top Angle	Bottom Angle
1	89.32°	89.32°
2	89.11°	89.11°
3	88.33°	89.33°
4	88.63°	88.33°
5	87.85°	88.22°
6	86.83°	87.48°
7	85.92°	86.67°
8	83.72°	84.91°
9	83.69°	83.83°
10	78.29°	84.31°
11	79.88°	79.88°

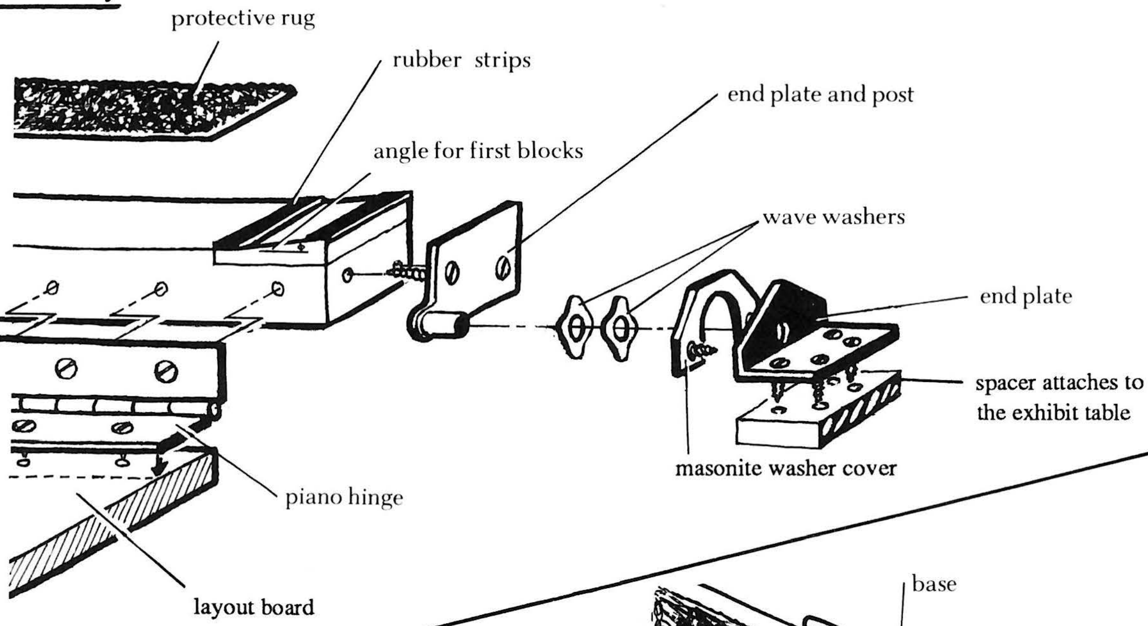
Angle tolerances approximately ± .05°

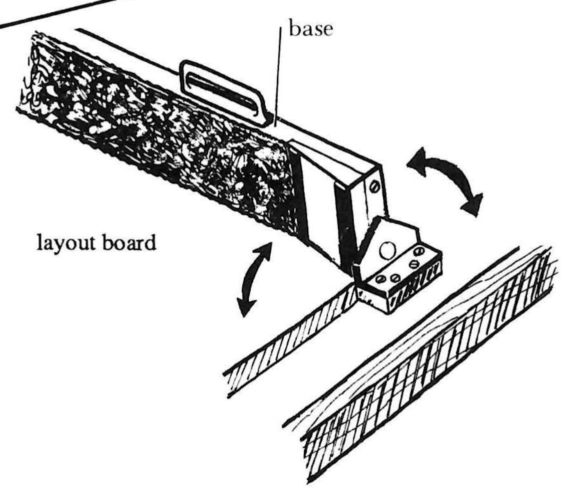
The block lengths were chosen rather arbitrarily. The end of each block must be cut at an angle such that the cut will be perpendicular to the centerline. The figure above shows the arch and its base; the accompanying table gives the angles for each of the blocks.

As the assembly diagram on the next page shows, the layout board is attached to the arch's base with a piano hinge. The base, in turn, is attached to the exhibit's table top by another pair of hinges, which we fabricated. This arrangement allows the base to be kept at 90 degrees to the layout board while the assembled arch is being raised. When the arch is standing, the board can be lowered while the base stays put, with the arch resting on it. Spring washers, which we have installed in the base's hinges, add a little friction to their movement. Note that the pins of the base hinge have been made to be in line with the pin of the piano hinge. Because of this, pivoting the base doesn't cause the board to move about. We have incorporated various adjustable stops into the design of the whole assembly to ensure that the base will be horizontal when the arch is raised and that the board will stay at 90 degrees during the raising. We have added a restrainer to the back of the board to ensure that the board cannot be forced beyond vertical when it is raised.

The blocks are made of maple. Some Cookbook users have

Hinge Assembly





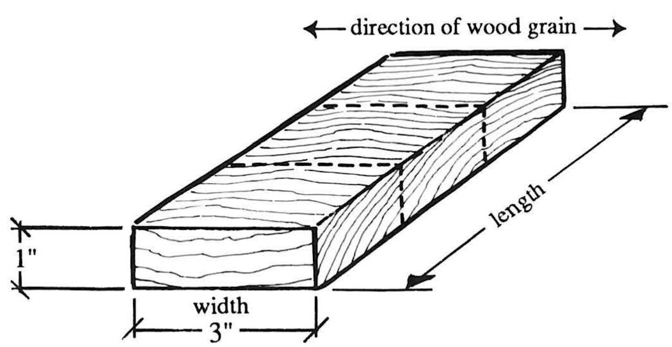
Completed Assembly

The hinge design allows both the base and the layout board to pivot 90° independently of each other.

had trouble making the blocks accurately at a reasonable cost. Here is the procedure we use:

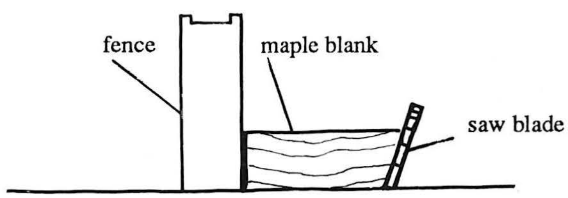
First, assemble the base and the layout board. You can make the layout board by using the drawing of the arch shown on the Exhibit Graphics at the end of this recipe (pg. 102-5). Enlarge this drawing to exactly four times its printed size. Take care that no overall distortion occurs in the enlargement. Check the size of your enlargement against the dimensions shown on page 102-2. Or you can order a full-size copy of the layout board from the Exploratorium for $75.00 for an unlaminated copy or $150.00 for a copy that has been laminated. Orders should be placed through the Exploratorium Store Mail Order Department, and customers should allow 6-8 weeks for delivery. (Contact the Exploratorium Store at 3601 Lyon St., San Francisco, CA 94123; telephone (415) 561-0393.)

Our finished blocks are 1" thick and 2" wide. The length of each block varies with its position in the arch. The ends of each block must be cut to the precise angles shown in the table. We make at least two blocks at a time (one for each side of the arch, except for block number 11). We usually make more than one set of blocks at a time, so that we have a replacement set on hand.



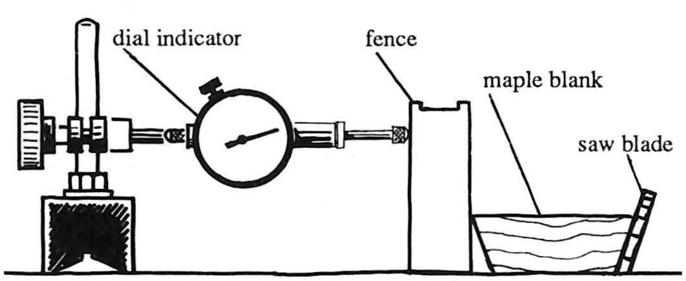
First, cut maple blanks like the one shown here. Here, we are defining length as the distance across the grain of the wood

and width as the direction parallel to the grain. The maple blanks are 1" thick, about 3" long (a little longer than the length of any completed block), and about 4.5" wide (wide enough so that you can cut at least two 2" wide blocks from each blank). This ensures that the grain of the wood will run the length of the completed block, which will make the blocks more durable.



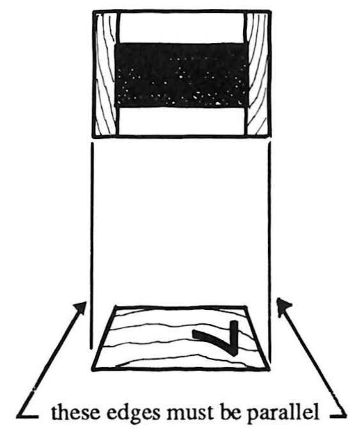
Using an accurate protractor, set the tilt of the blade on a table saw for the block face angle for block number 1 (from the table on page 102-2). Using the fence, cut this angle.

Turn the blank around and use the same procedure to cut the opposite face angle. To get the block length, use the layout board as a pattern. (It is convenient to use a dial-indicator mounted to a magnetic base as a means of adjusting the fence of the saw.) The blocks can now be cut from the blank. Continue in this way for successively higher block numbers. In this way, blocks can be cut to length with no accumulation of error.



The real virtue of the above procedure is that when the face angles are cut, you are assured that the edges of the faces will be exactly parallel. Minimizing this error is most important: as the blocks are stacked, any small angular error will (sometimes) accumulate and the arch will not stand.

The numbers on the blocks are embossed into the wood with heated number stamps. A broad black stripe is painted on the surface of the block that faces inward.



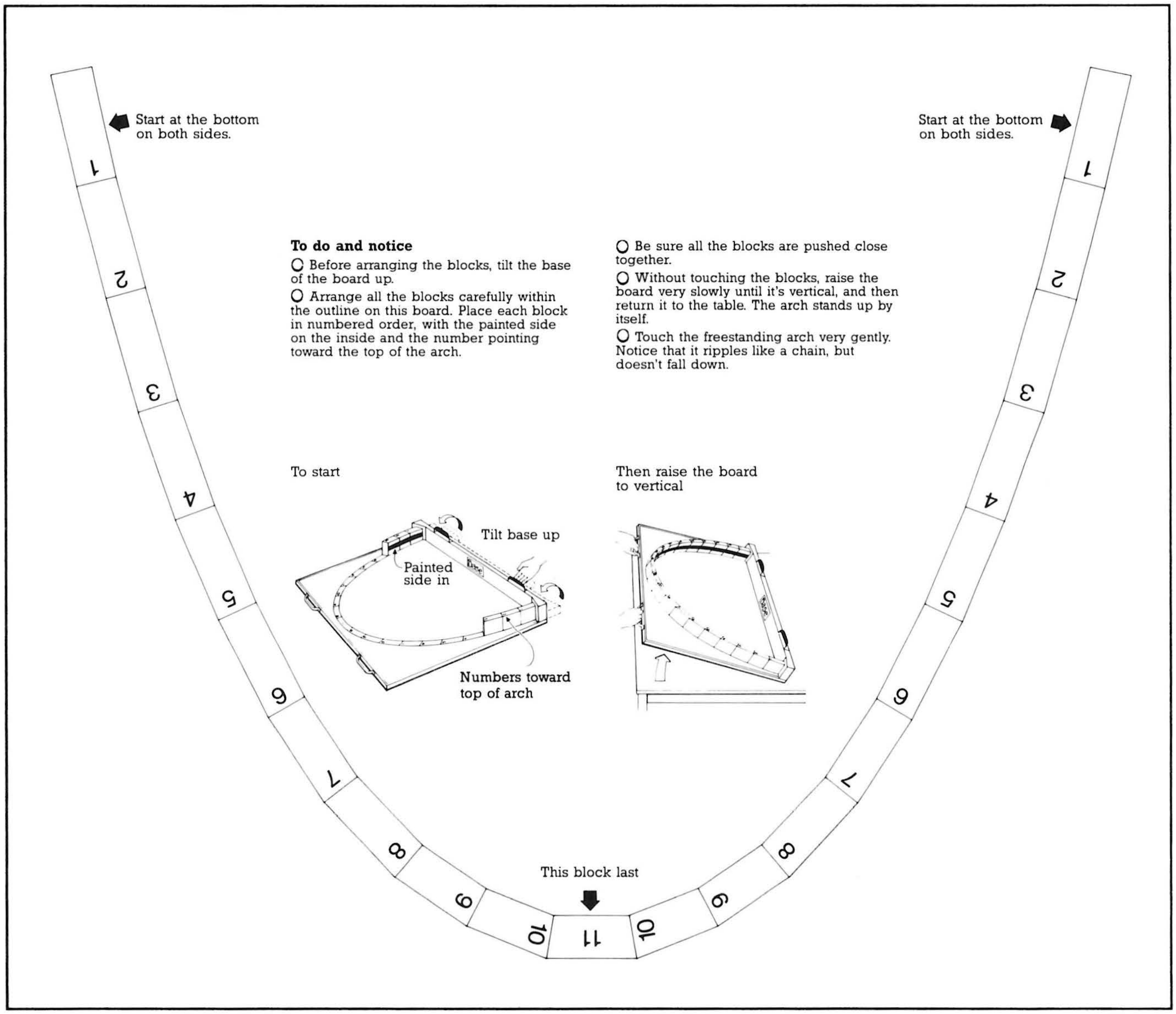
Minimizing the number of hard surfaces that the falling blocks can hit will prolong their life considerably. Happily, the blocks are very rarely lost or stolen, but they do get beat up after a while and must be replaced. We prolong their life by soaking them in a thin epoxy resin and then wiping away *all* the excess.

Related Exploratorium Exhibits

EXPONENTIALS AND LOGARITHMS

- **Air Pump**
- **Avalanche**
- **Capacitor Charge-Discharge**
- **Capstan**
- **Fading Motion**
- **Fading Tone**
- **Logarithmic Stacking**
- **Square Wheels**
- **Catenary Chain/Soap Film Analogy**

Exploratorium Exhibit Graphics



What's going on

When you suspend a rope or chain from two points, the chain hangs in a shape called a *catenary curve*. (The word "catenary" comes from the Latin "catena," meaning "chain.") Every segment of chain pulls on every other segment of chain, and this is what gives the hanging chain its shape. The chain is almost vertical near the points of suspension because this part of the chain has the most weight pulling down on it. As you move toward the bottom, the slope of the chain decreases because the chain is supporting less and less weight.

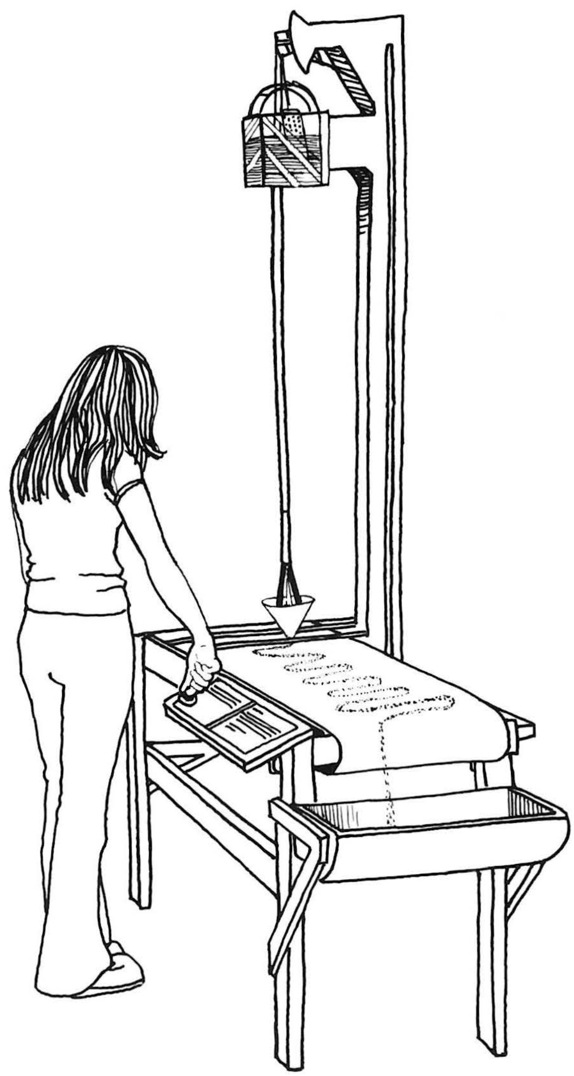
The arch is self-supporting because it is shaped like a catenary. Every block in the arch is held in place by the neighboring blocks. The blocks don't slide off each other, even at the top, because the forces between the blocks are along the curve of the arch itself. The blocks at the bottom of the arch are more vertical because they have more weight to support from the blocks above.

So what?

The stainless steel Gateway Arch in St. Louis, Missouri, is shaped like a catenary curve. The arch's ability to support its own enormous weight depends on the steel's ability to withstand being squeezed or compressed. The forces supporting the arch are compression forces directed along the arch.

Recipe No. 103

Fading Motion



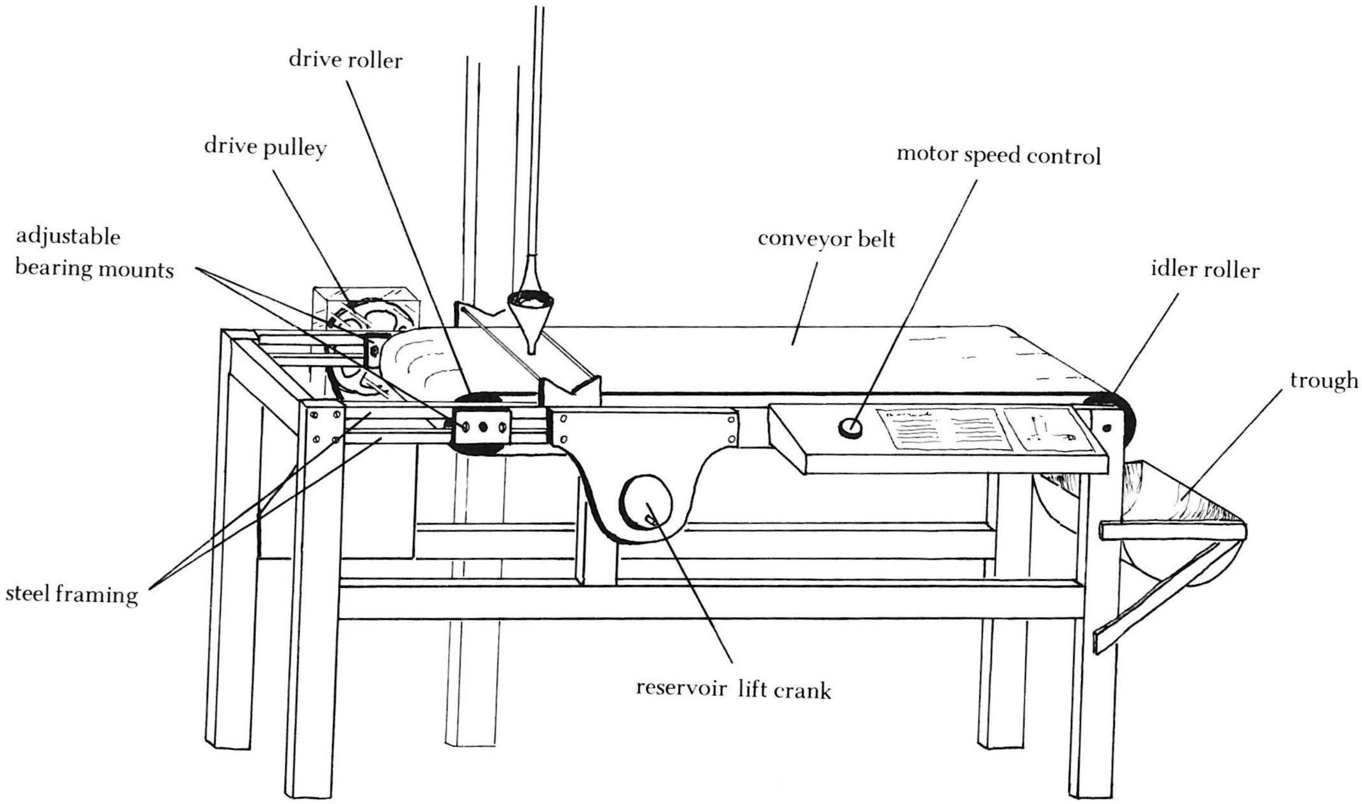
Description

A swinging pendulum pours sand from its "bob" onto a variable speed conveyer belt which moves in a direction perpendicular to the swing of the pendulum. The sand forms a wavy pattern on the belt which diminishes in amplitude exponentially due to a damping mechanism consisting of a paddle moving through thick oil. The oil reservoir may be raised or lowered (the paddle is fixed to the pendulum) to vary the amount of damping.

Construction

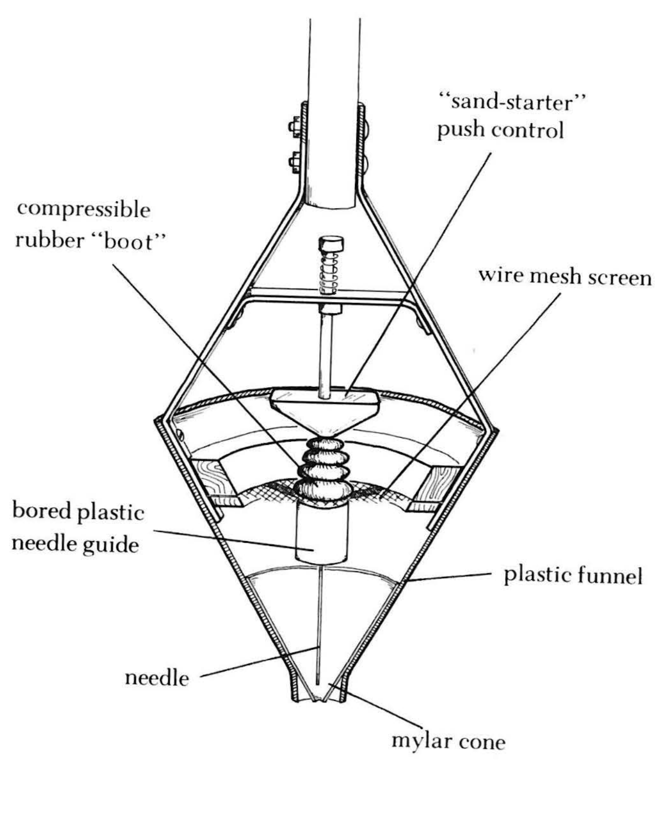
This exhibit consists of two main parts:
1) The table, drive assembly, and belt
2) The pendulum and damper

The conveyer belt is made for food processing and has a slick rubbery plastic surface on the outside and a rough cloth textured surface on the inside. Although we started using the slick side we found that it worked better if the belt was used inside-out on the rough side because the sand

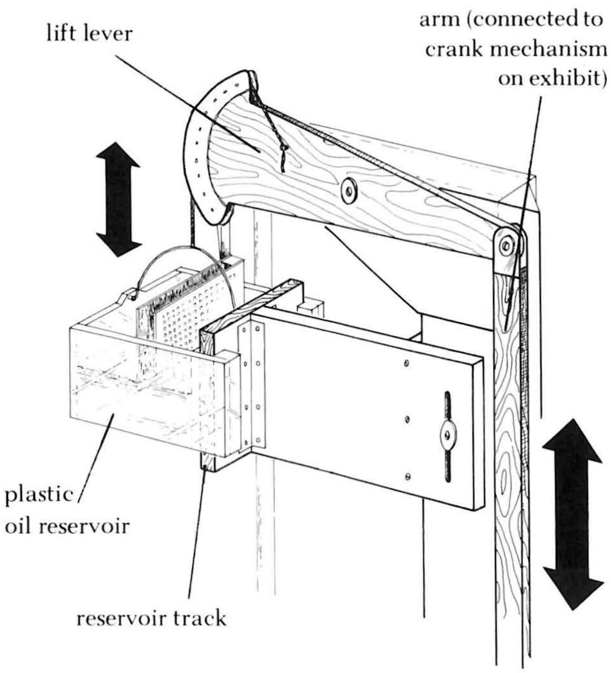


scattered less. The loop is 15" wide and about 96" in circumference. It can be made to your specifications and delivered already glued into a loop (look in the Yellow Pages under "power transmissions"). The drive and idler rollers are made of 4.5" OD PVC pipe with machined aluminum end caps. The drive roller has external bearings bolted to the steel frame of the table which can be moved to tighten and loosen the belt. The idler roller has standard bearings installed in the end caps. All bearings must be the sealed type because of the sand (bushings probably won't work). Both rollers are crowned by wrapping cloth tape around them, building them up at the center. This keeps the belt centered on the rollers. The drive roller is driven with a 3/8" v-belt drive with a 1:7 drive ratio (7" pulley on drive roller, 1" pulley on motor). The motor is a 110 VDC, 1/70 HP shunt wound motor with a speed reducer to 48 RPM (@ 110V). This motor was made

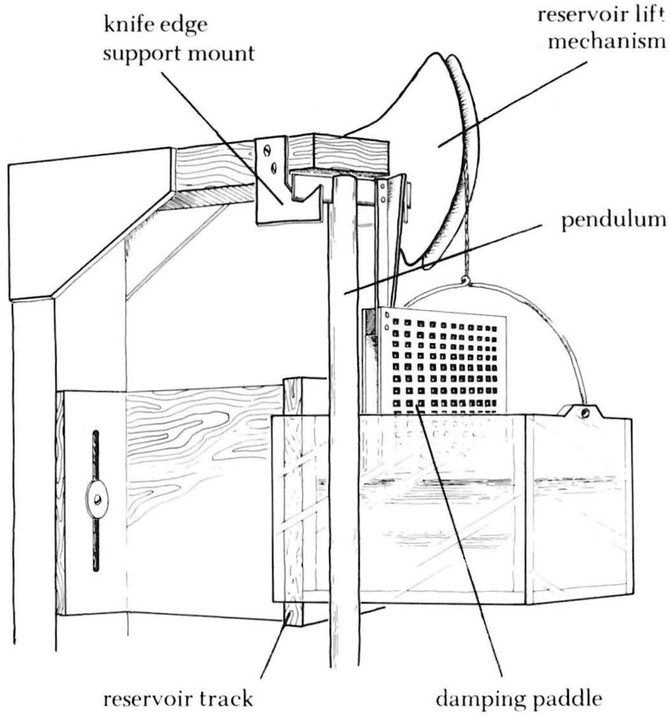
Funnel/"Sand-Starter" Detail



Reservoir Lift Mechanism



Reservoir/Pendulum support Detail



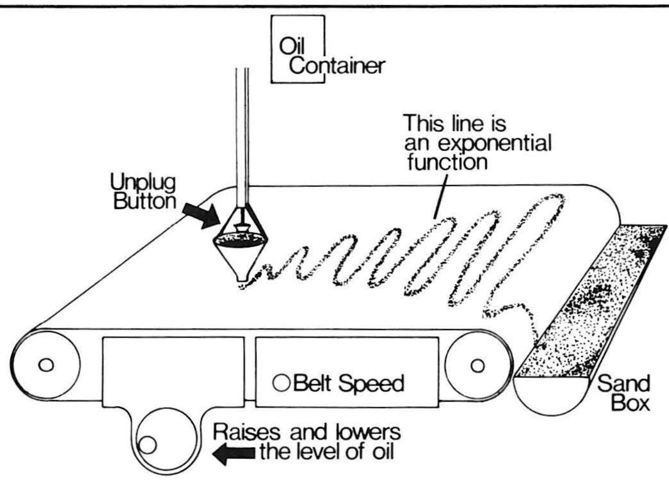
by Bodine, but another can easily be substituted. The speed of the motor is changed by varying the voltage to the armature windings of the motor and keeping the field windings at 110V. The motor and pulleys are shielded from seeking fingers with sheet metal and clear plastic sheet. The conveyer belt is stretched between the rollers and a board is mounted below its upper surface to keep people from pushing down on the belt. A trough placed at the end of the table catches the sand as it falls off of the belt. Some sand inevitably makes its way to the floor and we've placed a grooved rubber mat on the floor so people won't slip on the sand.

The pendulum is about 59" long and is made of 1" PVC pipe. To the bottom of the pipe a common plastic funnel was attached and a small cone of .010" mylar sheet with a small hole at its apex is placed at the orifice of the funnel to reduce its aperture and rate of flow. A spring loaded "sand starter" (which gets the sand flowing if something stops up the funnel) is positioned over the center of the funnel poking through a wire mesh screen around the top of the funnel which presorts the sand for large debris. The pendulum hangs from a pair of knife edges for almost frictionless support (see detail). The damping paddle also hangs from the knife edges and is made from two pieces of perforated sheet metal separated by 1". The perforations are necessary to maintain turbulence in the oil or else the damping will not be exponential. The oil used was old motor oil thickened with the addition of some 140 weight oil. The reservoir is made with polycarbonate plastic, glued together to form a box. The reservoir slides up and down on a wooden track activated by a crank on the front of the exhibit (see detail).

Related Exploratorium Exhibits

EXPONENTIALS

Fading Tone
Air Pump
Logarithmic Stacking
Catenary Arch



To do and notice

Turn the knob marked BELT SPEED to get the belt moving.

Be sure the funnel is filled with sand. (There is more sand at the end of the table.) If sand does not flow out of the bottom of the funnel, push the red button right over the funnel.

Bring the pendulum all the way toward you, into the notch of the STARTING PLATE, and then let go. Notice that each succeeding peak of the wavy line is lower than the one before it.

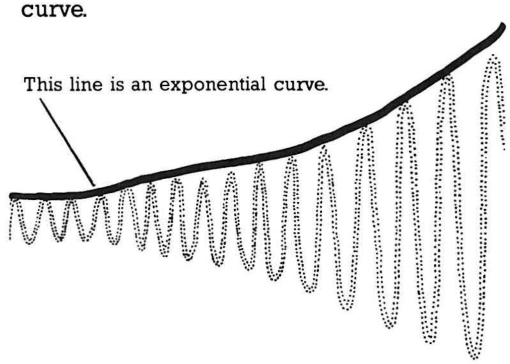
The pendulum is attached to a DAMPING MECHANISM, a perforated metal plate in a container of oil at the top of the exhibit. You can move this mechanism up and down the DAMPING SCALE by turning the crank on the front of the exhibit. Set the damping mechanism to different heights and notice the effect of the decreasing peaks.

What's going on

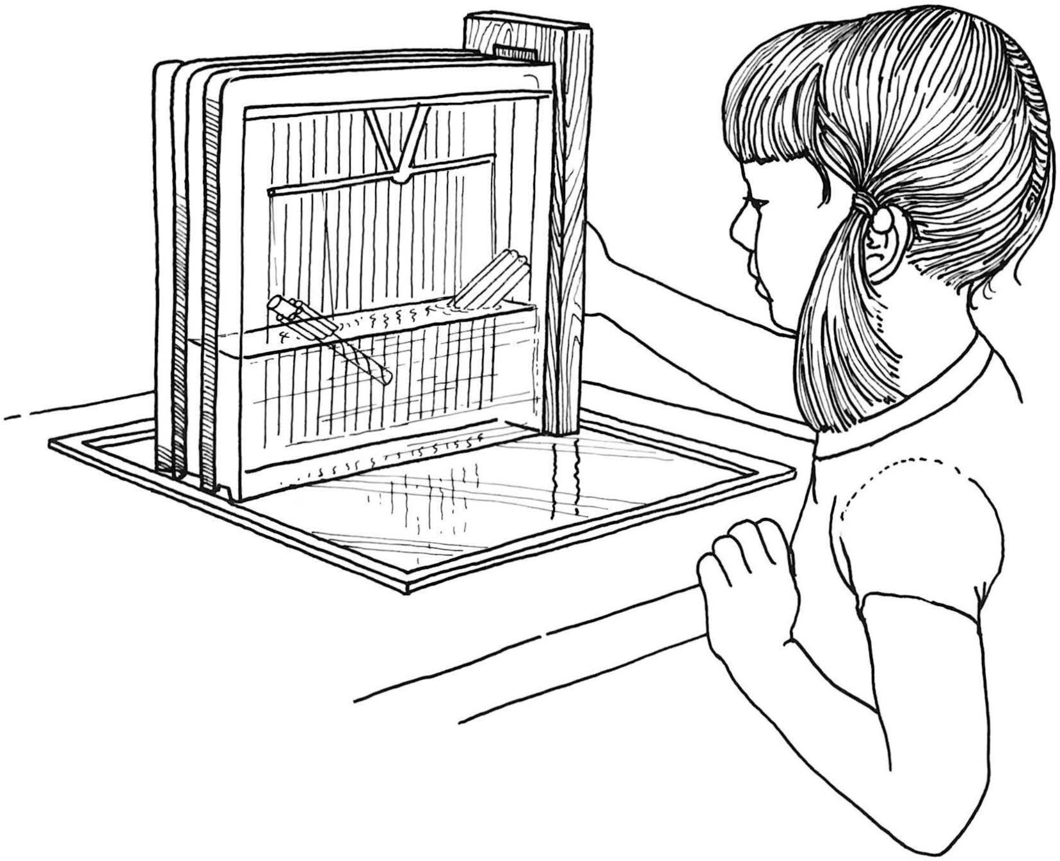
When the pendulum swings back and forth over the moving belt, the sand creates a wavy pattern. The peaks in this pattern get lower and lower as friction forces the pendulum to lose speed and swing in smaller and smaller arcs.

The pendulum always takes the same amount of time to return to its starting point and complete a cycle. Since the pendulum travels through a large swing in the same amount of time it takes to travel through a small swing, the pendulum must move faster through the larger swing. But the faster the pendulum moves, the more speed it loses. That's because the pendulum is attached to a metal plate that swings through oil. The faster the pendulum moves, the more friction there is between the metal plate and the oil, and the more speed the pendulum loses. The pendulum loses a fixed fraction of its speed on every swing. On the largest swing, the pendulum has more speed, so it loses more speed. On each successively shorter swing, the pendulum has less speed and therefore loses less speed.

As the pendulum loses speed, the pendulum's swings decrease in size according to a mathematical pattern. If you could compare the height of any peak to the height of the previous peak, you would always get the same fraction or ratio. Something that repeatedly decreases by the same ratio follows a mathematical pattern known as exponential decrease. A continuous line connecting the tops of the peaks would form an exponential curve.



Disappearing Glass Rods



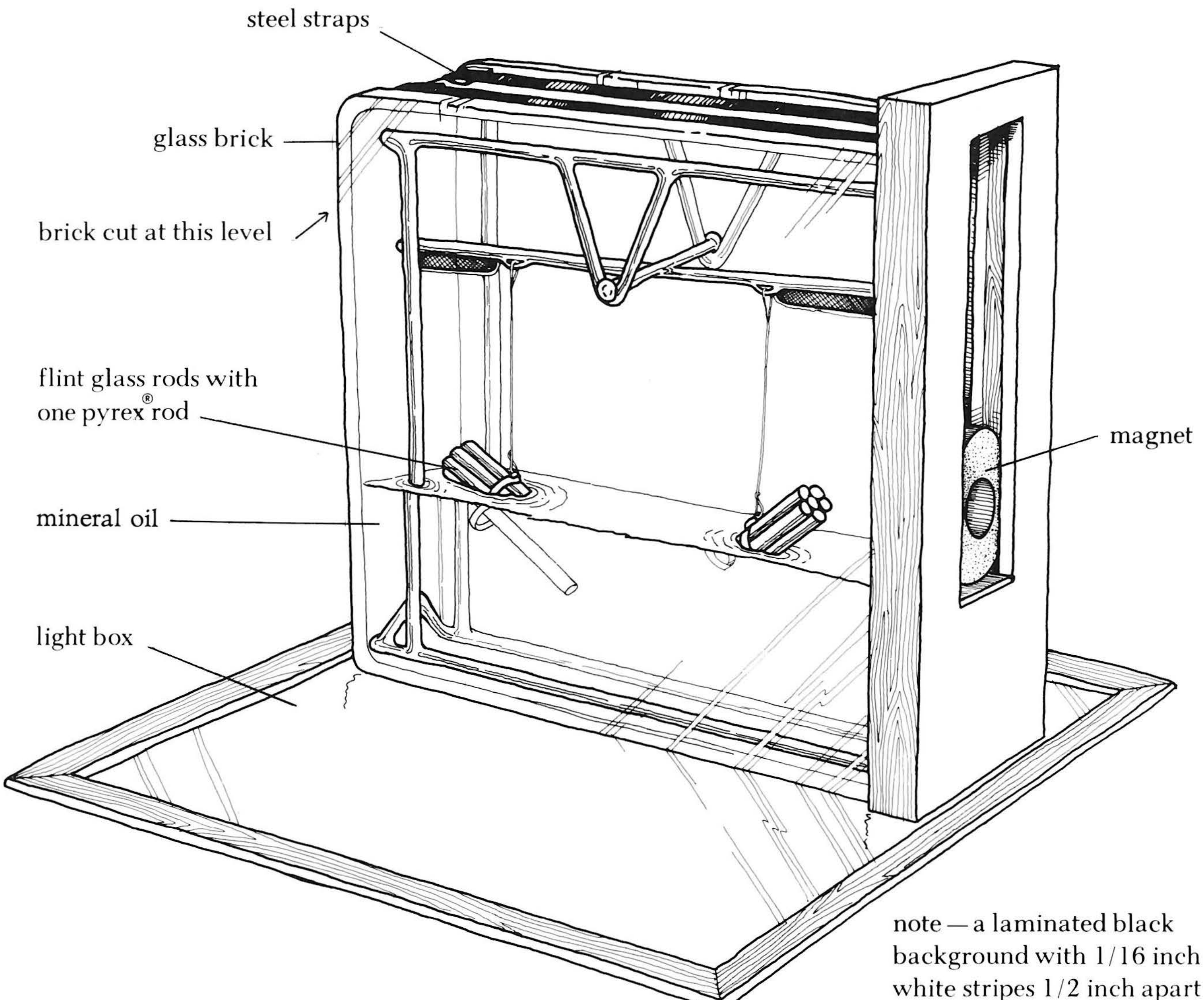
Description

Each of two bundles of glass rods is immersed in a clear liquid in a glass tank. One bundle disappears completely while the other disappears except for a single rod in the middle of the bundle. This is because all of the rods (except for the one that remains visible) have the same index of refraction as the liquid so that light passes through both the liquid and glass without bending. The rod with a different index of refraction bends the light and renders itself visible.

Construction

In past editions of Cookbook II we recommended a solution of anisole (dimethylphenolbenzene (n=1.515)) and monobromobenzene (n=1.557) in which pyrex and flint glass rods are dipped. These chemicals are carcinogenic and flammable. Because of this danger, we have found a better solution (pun intended): mineral oil.

We still use two different glass rods. One is flint or soda-lime glass (Kimble R-6) with an index of refraction n=1.52. The other is Pyrex (Corning



note — a laminated black background with 1/16 inch white stripes 1/2 inch apart heightens the effect

7740) with an index of refraction n=1.474. You can get these glass rods directly from the manufacturer but there will be a substantial minimum order. You might try a local laboratory glass blowing company.

To make the matching oil solution, we found two mineral oils, a light oil with an index of refraction lower than the Pyrex, and a heavy oil with an index higher than the Pyrex. These oils are mixed until the index of refraction matches the index of refraction of the Pyrex rods. This is best done by looking through a rod immersed in the solution with a horizontal line behind the rod (see diagram). When the indices match the line will run horizontally through the rod. You may see some color fringing around the edge of the rod. This is because one can only match the index of refraction for one wavelength or color of light. The other colors will be bent differently. It should be best when you see a blue line along one edge of the rod and a red line along the other edge. Be sure to do this procedure with the oils at the temperature

that the exhibit will be maintained at. The final index of refraction is very sensitive to temperature and you may have to thermostatically control the temperature of the oil in the final exhibit.

We found that the rods are slightly birefringent due to strains set into the glass during manufacturing. This birefringence will make the rods more visible even when the solution is matched. To solve this problem, the rods can be annealed (brought to a temperature just below melting) for a while. This releases any strain in the glass. Incidentally, you can see this strain if you place the rod at 45^{o} between crossed polaroids. The strain will show as stripes running the length of the rod.

To allow the visitor to lower and raise the bundles into and out of the liquid, the rods are hung from a "see-saw" made of glass rods that have been heat bent and fused. Materials other than glass may be used for the see-saw as long as they don't interact with the oil. Bar magnets attached to the ends of the see-saw act to balance the mechanism and provide mechanical coupling to the outside of the tank. The user can move a magnet up and down in a wooden track next to the tank to tip the see-saw.

Although there are suitable chromatography tanks available, we adapted an economical ($10) glass brick to our purposes. The brick must be smooth front and back (many are rippled). The top of the brick was removed with a diamond saw about 1.5" from the top, filled, then resealed with silicone seal. A striped background placed inside the back of the tank aids in the visibility of the rods. It was made by applying white graphic tape to black paper, then laminating it in clear plastic to protect it from the liquid.

The tank is securely fastened to the table with 2 stainless steel straps. A light box below the tank is used to illuminate the exhibit and enhance the effect. The light source, a 40 watt circular fluorescent lamp, is mounted on a sheet of aluminum that serves both as reflector and ground for the lamp. Silicone seal, applied around the edges of the translucent white plastic top of the light box, protects the lamp from oil spillage should the glass brick break. A light blue gel under the plastic provides a sufficiently monochromatic, restricted illumination that greatly reduces the dispersive (prism) effect that could render the otherwise invisible glass visible.

Critique and Speculation

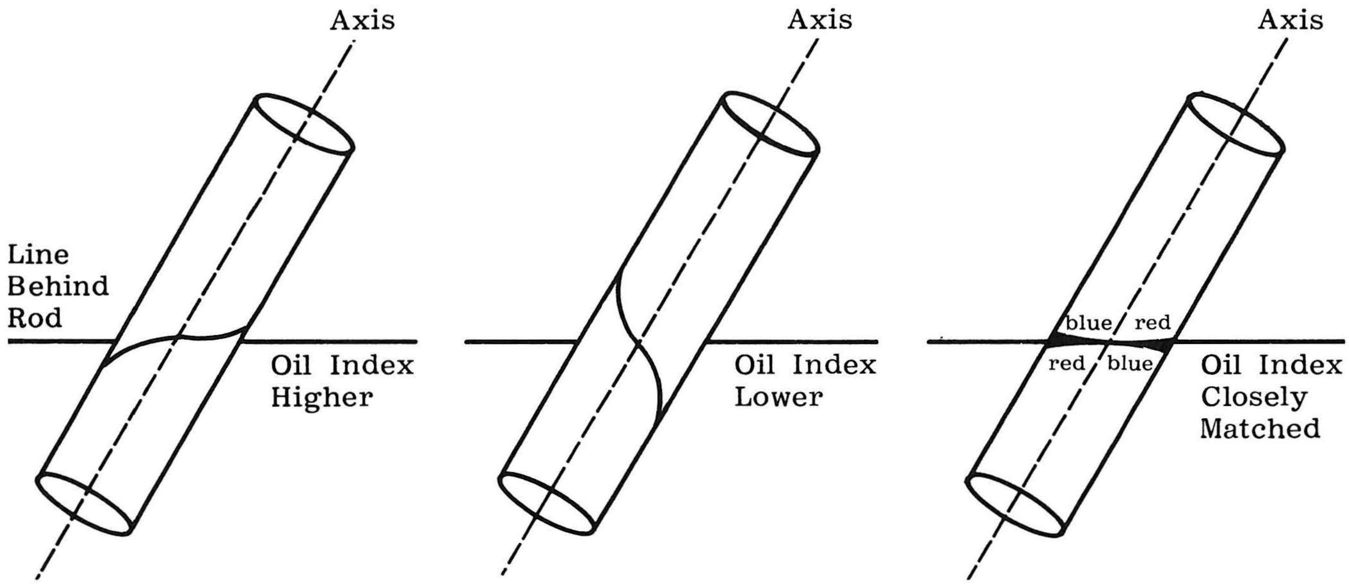
As mentioned above, the solutions suggested in previous editions of CookBook II are extremely hazardous. If you have made the exhibit with these chemicals, we suggest that you dispose of them properly and redo the exhibit with mineral oil.

Once the noxious chemicals have been banished, the construction of the tank is simplified. It may now be made of plastic, and the magnet arrangement for pivoting the see-saw may be replaced with a knob-and-axle through the front and rear of the box. The magnets were used to avoid holes in the tank through which poisonous vapors could escape. With mineral oil, this is unnecessary. This knob is also much easier for the public to see and use.

Related Exploratorium Exhibits

REFRACTION

Critical Angle
Lens Table



Exploratorium Exhibit Graphics

To do and notice

Slide the ring magnet in the wooden track to raise and lower the glass rods hanging from the balance arm.

Observe the rods immersed in the liquid (mineral oil).

Notice that the bundle of rods on the right seems to vanish completely, while one rod is still visible in the bundle on the left.

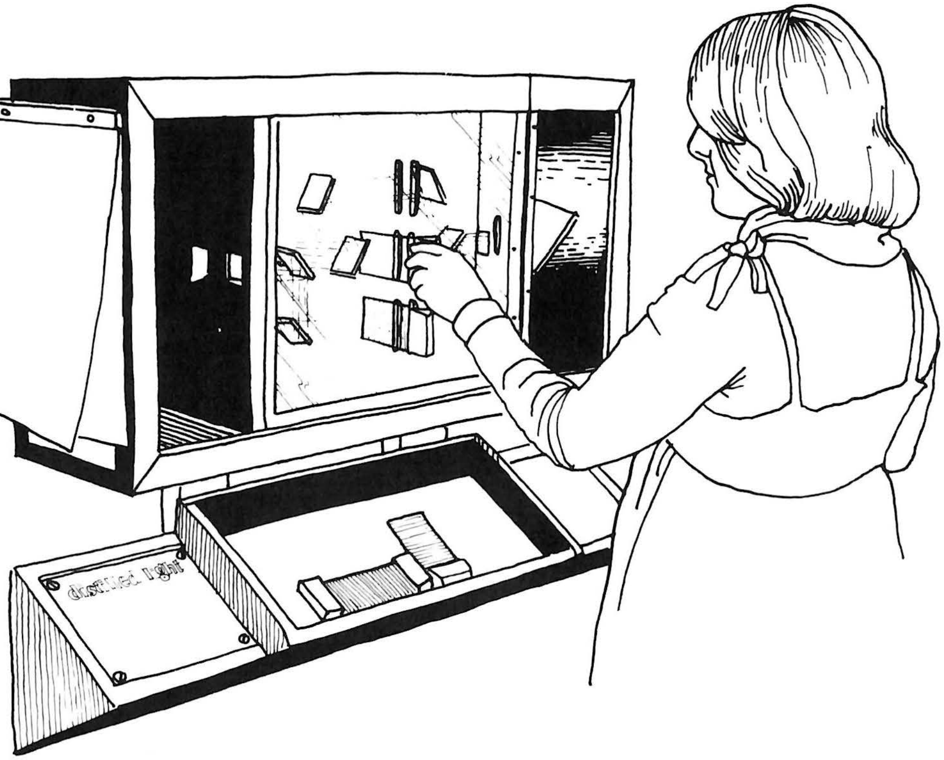
What is going on:

We can see glass objects even though they may be perfectly transparent, because light waves change speed when going from glass to air or air to water. When light (or any waves) changes speed in going from one medium (such as air) to another medium (such as glass) some of the light is reflected no matter how transparent the substance. We "see" glass because of this reflected light. The glass rods disappear in this exhibit because the light is going at the same speed in the liquid and in the glass. The light travels at a different speed in the one rod which is still visible when immersed in the liquid.

Disappearing glass -- flint glass; liquid -- mineral oil
Non-disappearing glass -- pyrex glass

Recipe No. 105

Distilled Light



Description

White light is broken up into the primary colors red, blue, and green by dichroic filters, and then recombined with similar filters into white light again. The visitor can experiment with color mixing by blocking or filtering the light before or after it has been broken up.

Construction

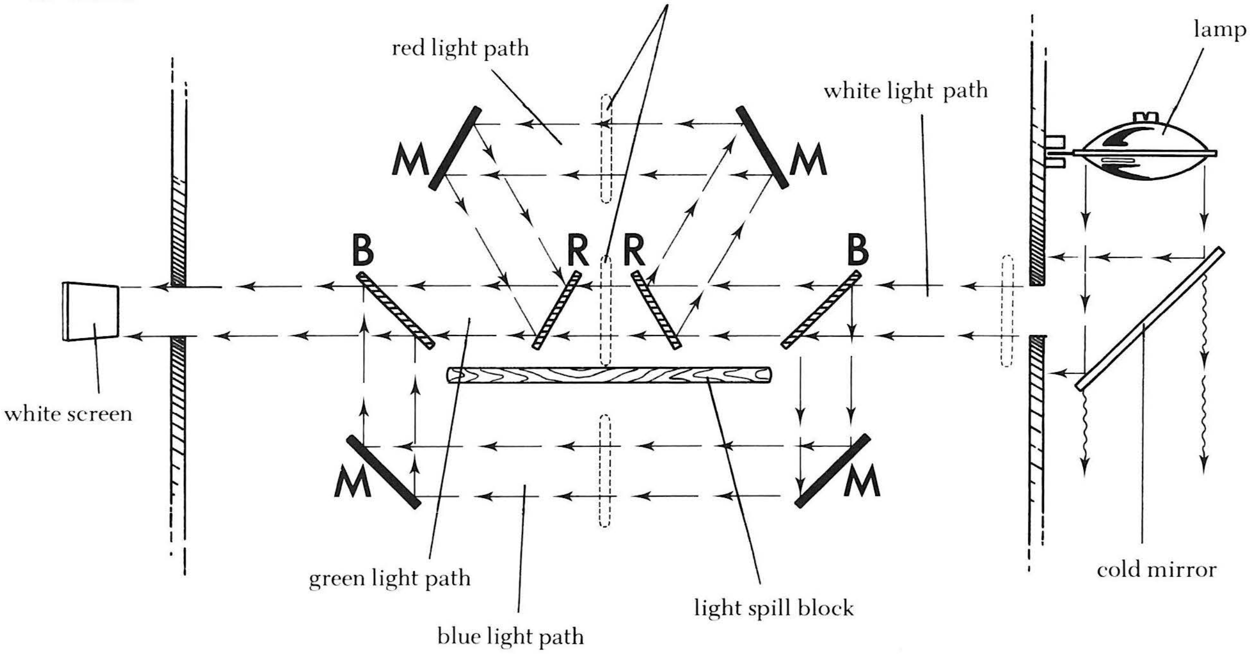
The exhibit can be divided into three main parts, each of which will be discussed separately. These are the filter box, the light source, and the exhibit stand.

The filter box contains all of the dichroic (reflects one color, transmits the rest) filter mirrors and their mounts. Two types of filters are needed, one that reflects red only, and one that reflects blue only. Two of each type are needed, one set to separate each component out, and the other set to recombine the colors. They are available from:

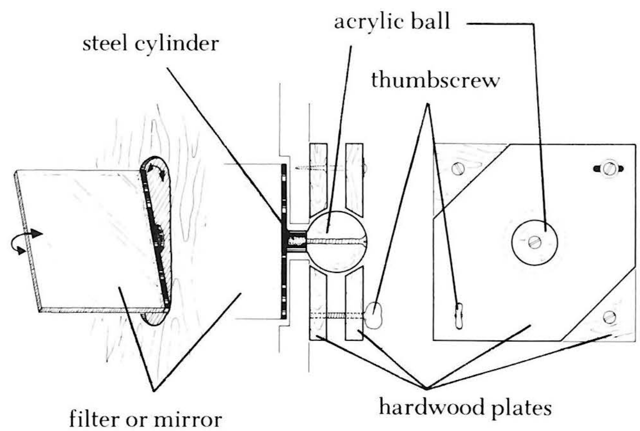
Optical Coating Laboratories, Inc.
2789 Northpoint Parkway
Santa Rosa, CA 95407-7397
(707) 545-6440

The filters are arranged as shown in the diagram. The filters are mounted on a "ball and socket" type of mounting (see diagram) which allows them to be both tilted forward and back as well as rotated to facilitate alignment. The

Filter/Mirror arrangement
Key: B - blue reflective filter
R - red reflective filter
M - mirror



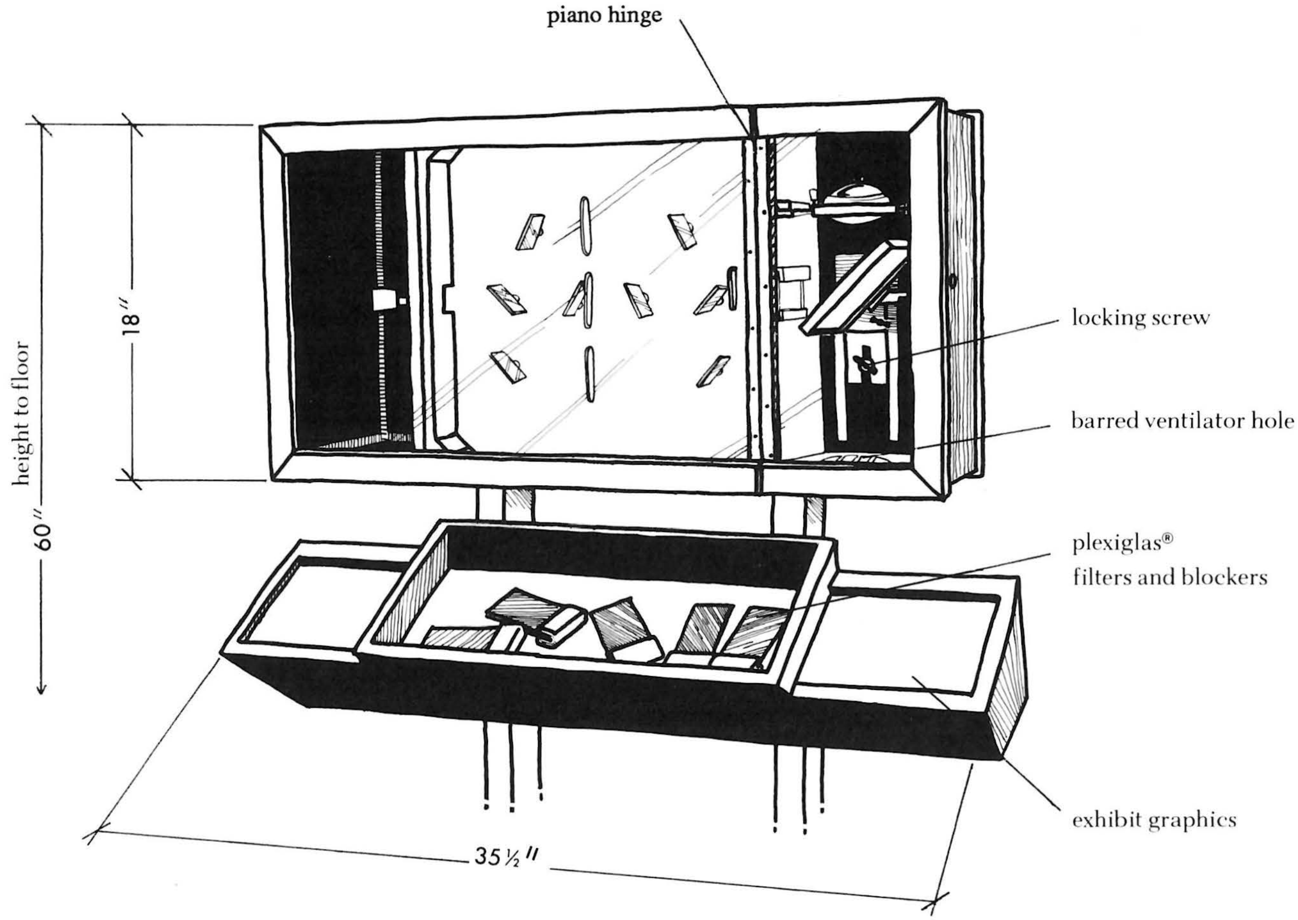
delicate glass filters are attached to the mounts with clear epoxy. To prevent light from spilling underneath the filters, they have been recessed into routed slots on the surface of the box approximately 1/16" deep. The inside surface of the optics box is painted flat white to reflect the light and make the path of each "beam" visible. This surface must be very flat as surface deformities are revealed by the glancing angle of the light. To prevent the red beam from spilling into the blue, a small block of wood is mounted under the green beam (see diagram). The entire optics box is easily removable from the exhibit for repair, held in with only four bolts. Covering the entire front of the exhibit box is a frame which holds a double layer of 1/4" plexiglas®, spaced 2" apart and slotted to allow the plexiglas® filters to be inserted into the path of the light at several places. The double layer prevents the filters from being rocked from side to side, possibly hitting the delicate glass dichroic filters. This cover is bolted



detail of filter "ball and socket" mount

to the front of the exhibit, but should have been hinged instead. The plexiglas® filters have small wooden handles screwed onto them and this discourages theft of them since they then look as if they are part of the exhibit.

The light source, located next to the optics box, employs a No. 4509 13 volt, 100 watt, PAR 36 aircraft lamp in a mount which slides forward and back as well as left and right. This allows a portion of the beam without any shadow



from the filament mount to be selected for use in the exhibit. The light from the lamp shines down on a dichroic "cold mirror" which reflects the visible light into the optics box while transmitting the infrared through a barred (with aluminum rods) hole in the bottom of the box (people can put their hand under the hole and feel the heat). The box is also ventilated above the lamp through a screened hole. The transformer for the lamp is mounted in a compartment in back of the exhibit. The cold mirror is mounted on a wooden ball and socket to provide easy adjustment. All adjustable things can be tightened down after final adjustment with locking screws (wingnuts on studs).

The exhibit stand is made of wood and is weighted in the rear with a cylindrical cement weight. The weight is attached to the exhibit with an axle which runs through the weight's center. This allows easy removal of the weight. Since the exhibit box is mounted rather high, a step split in the middle is provided for children. The split step is easy for kids to straddle while also allowing adults to stand close to the exhibit. A light box is bolted onto the stand and provides a place to store the unused plexiglas® filters and blockers. The light box makes the filters easily visible while also providing a place to mount rear lit graphics. Lamps are replaced through the bottom door running the length of the box and bolted shut.

All non-optical surfaces in the exhibit (except for parts of the legs) have been painted flat black to reduce reflections.

Critique and Speculation

Kids often treat the exhibit roughly and knock the optics out of alignment, necessitating adjustment. This happens about once a week, but it only takes a minute to adjust. As with any optical system, the optics need cleaning and/or dusting periodically.

Additions and Changes (1990)

The biggest maintenance problem in our design of this exhibit is the light source. If you want to build this exhibit, we recommend that you use an old slide projector for your light source, since this will provide an even field of near-white light. Even with a slide projector, you will probably need to adjust the color of the light slightly, to make it as white as possible. We suggest placing a theatrical gel in front of the light. To figure out what gel will work for you, you will want to experiment with the palest possible theatrical gels. Try gels from different manufacturers, until you find the right one.

Related Exploratorium Exhibits

COLOR

- Bridge Light
- Soap Bubbles

COLORS (COMPLEMENTARY)

- Color Sum
- Colored Shadows

Exploratorium Exhibit Graphics

distilled light

● follow the path of the white beam of light from the right as it passes through a series of interference filters to the screen on the left.

● insert a blocking panel in the central slot to block off the green... you will get a purple light on the screen at the left.

● insert different colored gels in the right-hand slot (or look through them) to see which colors these gels transmit and which colors the gels absorb.

Interference filters fractionate the beam of white light coming from the right, reflecting one of the color bands in white light and allowing the remaining colors to pass through.
The first filter reflects out the blue, leaving yellow light; the second filter reflects the red-orange in the yellow light.
Green passes through all the filters.

The reflected beams of blue and red-orange are brought back together by another series of interference mirrors which reconstruct the white light.

see side of exhibit for more information

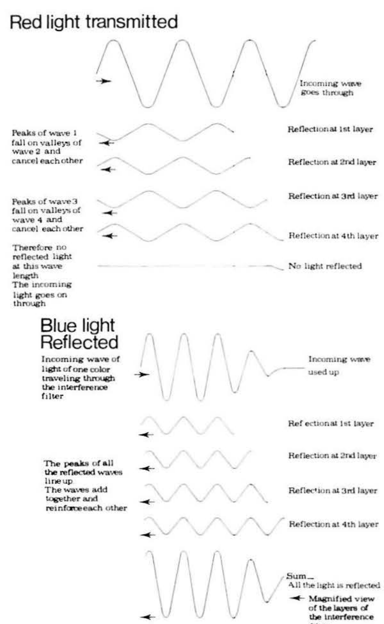
Interference Filters

Interference filters are plates of glass coated with many thin layers of transparent material. Light reflected from the surfaces of these layers becomes colored much the same way that soap films or layers of oil on water are colored. The crests of light waves reflected from the front surfaces of each layer can mesh with either the crests or the valleys of the waves reflected from the back surface of the layer. If crest falls on crest as in the diagram, the reflected wave is brighter, but if crest falls on a valley, the wave is nullified and no light of that color appears in the reflected beam. It all goes through the filter. The many layers of an interference filter all have this effect. A soap film has only one layer. The effect of the many layers is cumulative so that interference filter colors are brighter and purer than soap film colors.

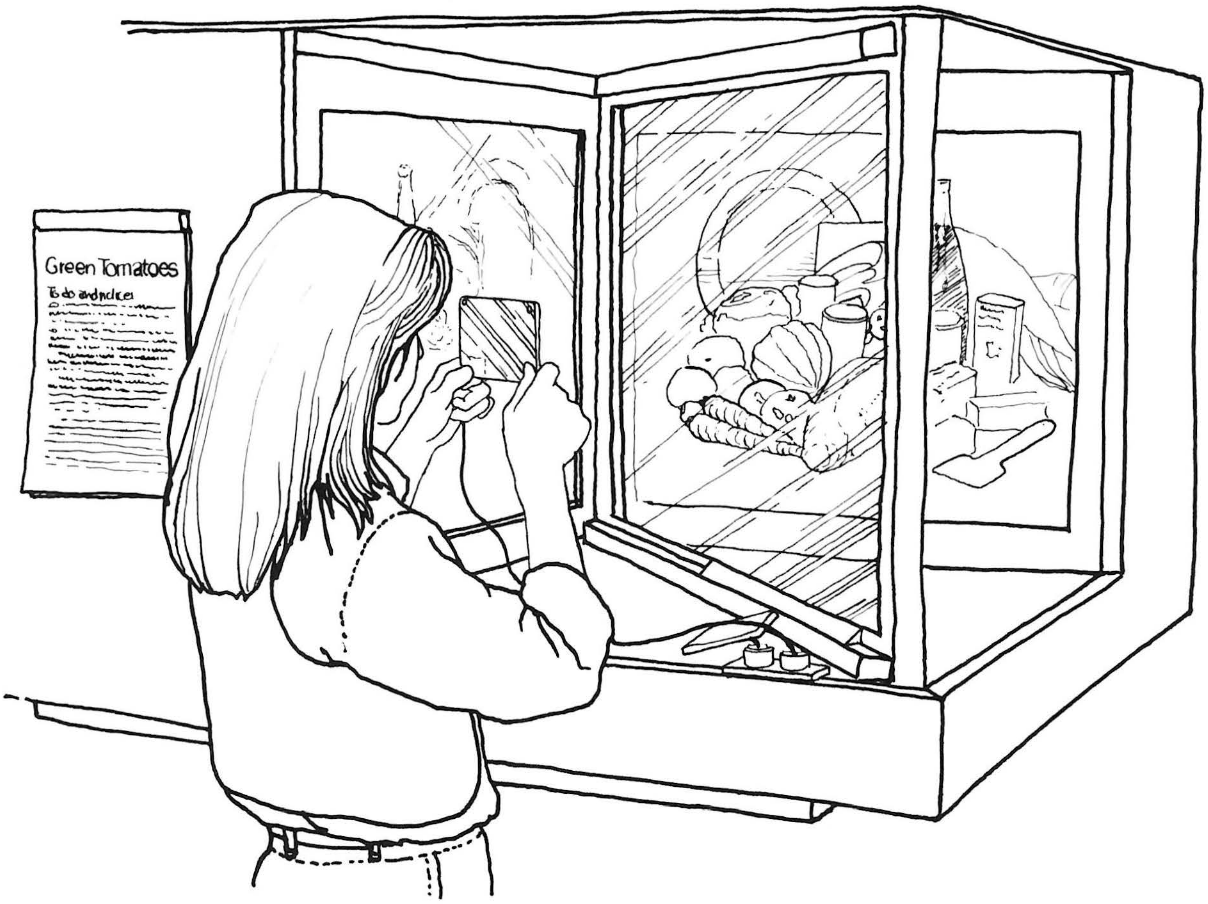
The particular color reflected by an interference filter depends on the thickness of the layers compared to the wave length of the light, the material used to make the layers, and the angle at which light strikes the filter.

The mirror under the light also is an interference filter. This mirror reflects most of the white light (except for a bit of green), but it allows most of the longer length heat rays to pass through the mirror and out the hole at the bottom of the case. You can feel the heat if you hold your hand beneath the case.

Interference filters differ from colored glass or gels, because interference filters do not absorb any light. Colored glass and gels absorb that part of the light that is not transmitted. The absorbed light is converted into heat.



Green Tomatoes

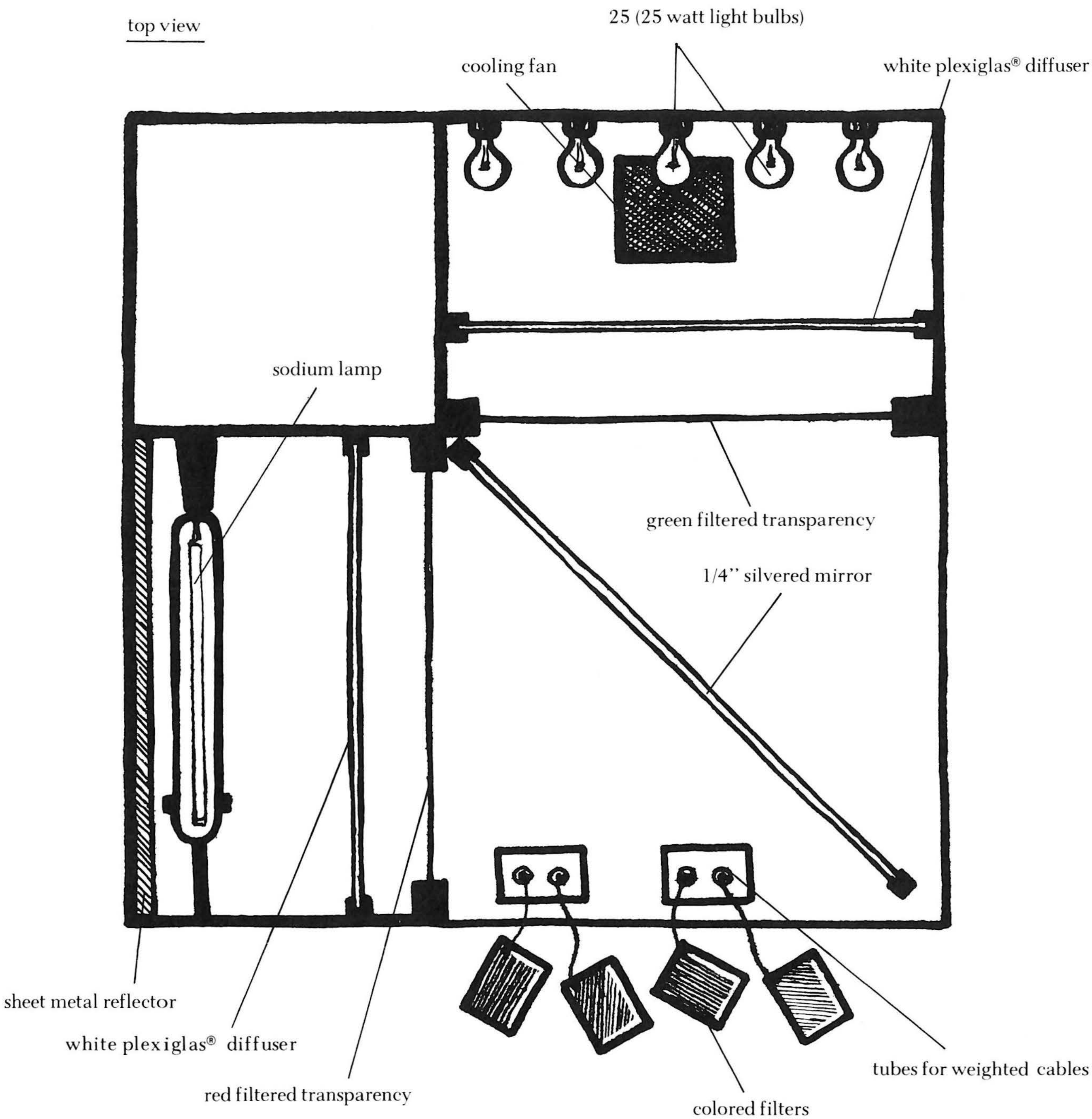


Description

Green Tomatoes is an exhibit dealing with the brain's amazing capability to provide additional information to fill in deficient perceptual cues. The visitor stares at a still life picture through a green filter and sees the photo in full color. The picture is actually a combination of two black and white transparencies, one illuminated with white light and taken through a green filter and another illuminated with monochromatic yellow light which was originally taken with a red filter. Our tranparencies are 38x24 inches and were donated to the museum. The explanation of why the visitor sees the picture in full color is very complicated and will not be discussed here (the reason is only a theory anyway!).

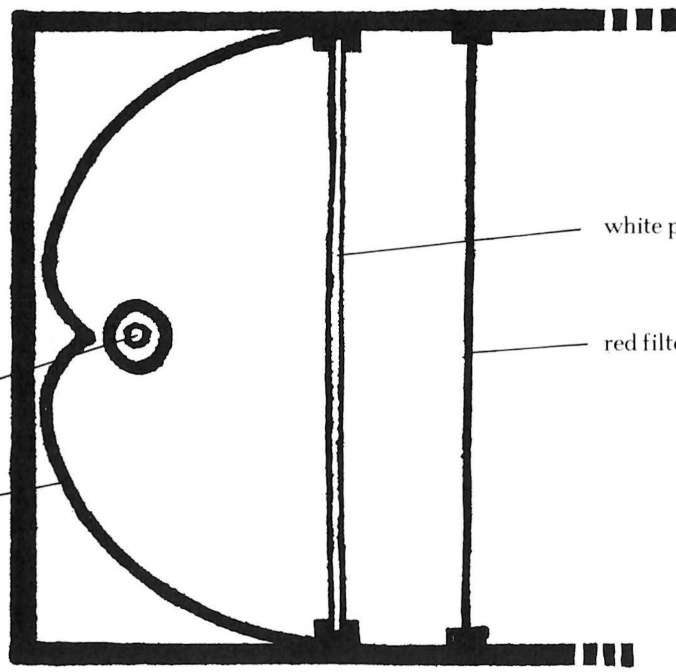
Construction

To combine the two transparencies, both of them were mounted in a large plywood enclosure at right angles to each other. Between them and at an angle



of 45 degrees is placed a 50-50 half "silvered" (the coating is actually chromium) mirror. When illuminated from behind, both transparencies may be viewed together, one reflected in the mirror and the other seen through it. Since the reflective coating is on only one side of the 1/4" thick mirror, the image may only be viewed aligned in one side of the mirror. To align the transparencies, they are hung from a frame with screws that allow vertical adjustment. This whole assembly is then mounted on a rail with horizontal adjusting screws and is spring loaded to hold everything in place.

reflector detail



The illumination for the green filtered transparency is provided by an array of 25, 25 watt rough service incandescent lamps layed out in a 5x5 array. In front of this array, 13" from the baseboard, is a 1/8" white plexiglas® diffuser with the transparency 5" in front of it (18" total). The red filtered transparency is illuminated with a Phillips SOX 90 watt low pressure sodium lamp. This tublar lamp is mounted horizontally with two cylindrical sheet-metal reflectors above and below it. The spacing for the white diffuser and transparency are the same as above. Both of the lamp compartments are fan cooled.

Various colored filters are hung on retractable vinyl coated steel cables from the front of the exhibit.

Critique and Speculation

Since our transparencies were donated, we have no procedures to make new ones. It should be a simple procedure to take two negatives with a large format camera (8x10), one with a green filter and the other with a red filter such that the resulting density of the negatives is about the same. Blow-ups of virtually any size could be made from such negatives.

Additional information on these effects and how to produce them can be found in two articles by Edwin Land:

Experiments in Color Vision
Scientific American, May 1959

The Retinex Theory of Color Vision
Scientific American, December 1977

Related Exploratorium Exhibits

COLOR VISION

Orange Shadows

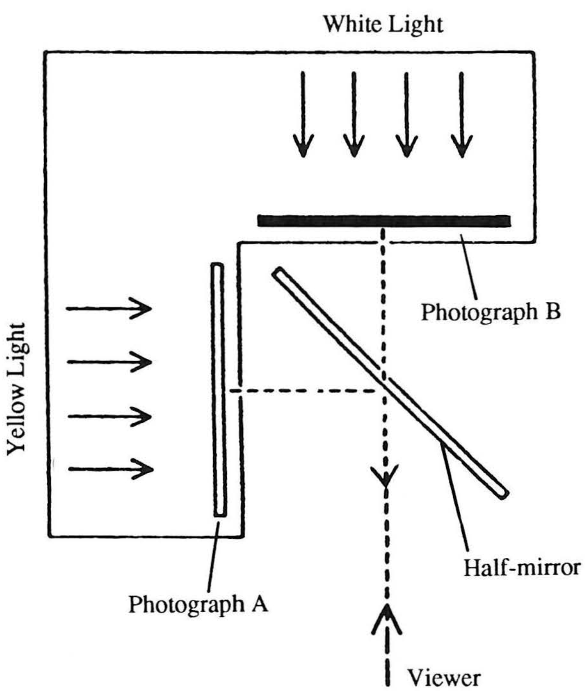
Your visual system can create a full palette of colors from just two colors of light.

To do and notice

•Look at the half-mirror through the green plastic. Notice that you see a multi-colored scene: red tomatoes, green boxes, etc.

•Put down the green plastic. Look at photo A. Notice that it's yellow. Look around the half-mirror at photo B. Notice that it's white. The half-mirror blends photos A and B.

•Hold up the red plastic and look at the half-mirror. Notice that the colors in the scene change. The tomatoes, for instance, are now green.



What's going on

The green plastic lets two colors of light—green and yellow—pass through to your eyes. The yellow light comes from photo A. The green light comes from photo B. (The white light behind photo B is made up of all the colors of the rainbow. The green plastic lets through the green part of this white light.) But when you look through the green plastic, you don't see just green, yellow, or greenish-yellow. Your eyes and brain create a full-color scene.

Your visual system tends to assign the color white to the lightest feature in your field of view—*even if there's really no white light reaching your eyes.* In this scene, the jar lids are among the brightest details, so they appear white. The jar lids let through more green and yellow light than any other feature. Now look at the tomatoes. Notice that they're transparent on photo A but dark on photo B. Lots of yellow light passes through the clear tomatoes on photo A and reaches your eye; very little green light makes it through the dark tomatoes on photo B. Other features let through different amounts of green and yellow light. In this exhibit, your eye and brain assign colors to the objects by comparing the relative amount of green and yellow light coming from each feature.

Researchers aren't exactly sure why you see the colors you do. Your visual system seems to compensate for the colors, or wavelengths, of light that are missing. When you hold up the green filter, a short wavelength of light—green—and a medium wavelength of light—yellow—reach your eyes. What's missing to make a full spectrum is a longer wavelength of light. Your visual system adds a long wavelength—red—to the scene. The tomatoes take on a reddish hue.

SPECTRUM

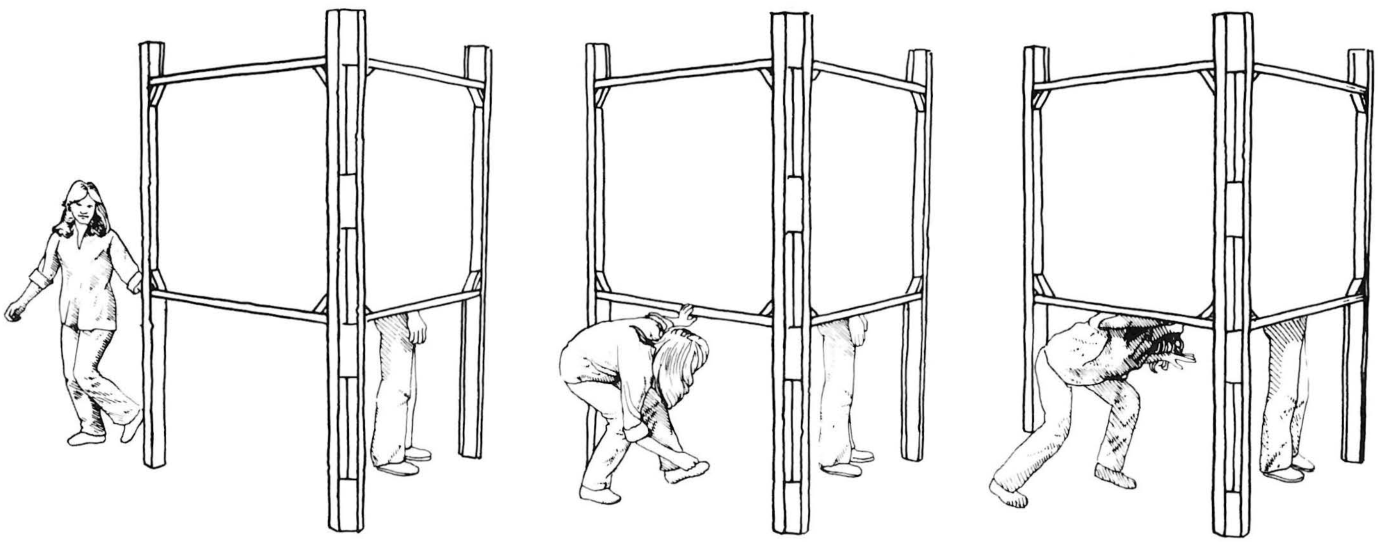
violet	blue	green	yellow	orange	red
<< shorter wavelengths			**longer wavelengths >>**		

When you look through the red plastic, you get the opposite situation. The red plastic lets through a longer wavelength of light—red—and a medium wavelength—yellow. What's missing is a shorter wavelength of light. Your visual system adds a short wavelength of light—green—to the scene. The tomatoes take on a greenish tinge.

So what?

Scientists used to think our eyes needed at least three colors of light to see a wide range of colors. This rule holds true when you're mixing meaningless blobs of light on a screen: you need a red light, a green light, and a blue light to create all the rainbow colors. But Edwin Land, inventor of the Polaroid camera, showed that when you pass lights through transparencies of a natural scene, you only need *two* colors of light to see a wide spectrum of colors.

Duck Into Kaleidoscope



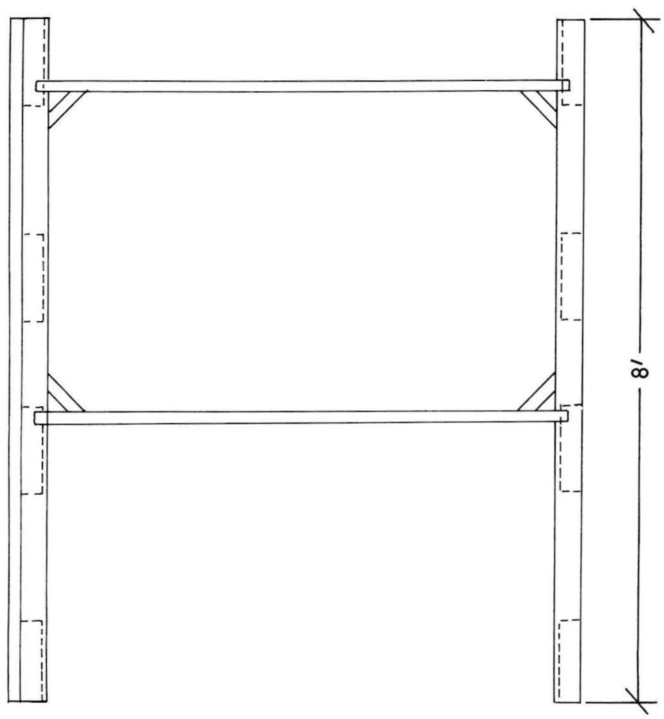
Description

The visitor ducks under one side of a large 3 sided wooden enclosure whose inner surfaces are covered with mirrors. Myriads of reflections of the person, the mirror corners, and the museum visible above and below the mirrors stretch off into the distance.

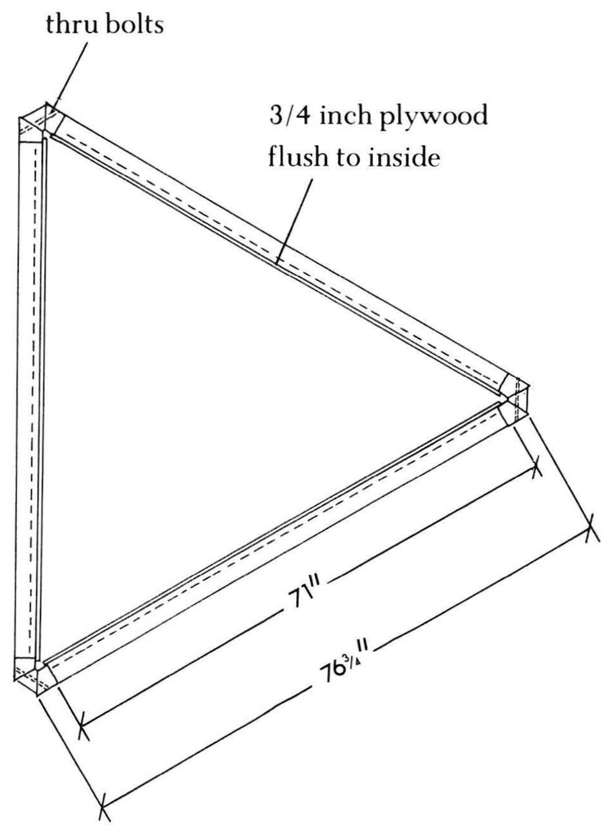
Construction

The Duck into Kaleidoscope is made from three large 4x6 foot mirrors arranged in a 60 degree equilateral triangular prism. The mirrors are glued with contact cement to a layer of 3/4" plywood. The backed mirror is then placed in a frame (with integral legs) made of fir 2x4's (top and bottom) and fir 4x4's (sides/legs). The 4x4's are cut at a 60 degree angle (see diagram) which allows the edges of the mirror to abut. The three sides of the exhibit then bolt together with large bolts through the 4x4's and 60 degree wedges (4 at each joint, each wedge 10" long) added for strength. The mirror has an oak molding around the top and bottom edges for appearance and to protect the edges of the mirrors. The bottom of the mirror is 40" above the floor allowing wheelchair access (albeit awkward) to the exhibit.

elevation view



top view



Critique and Speculation

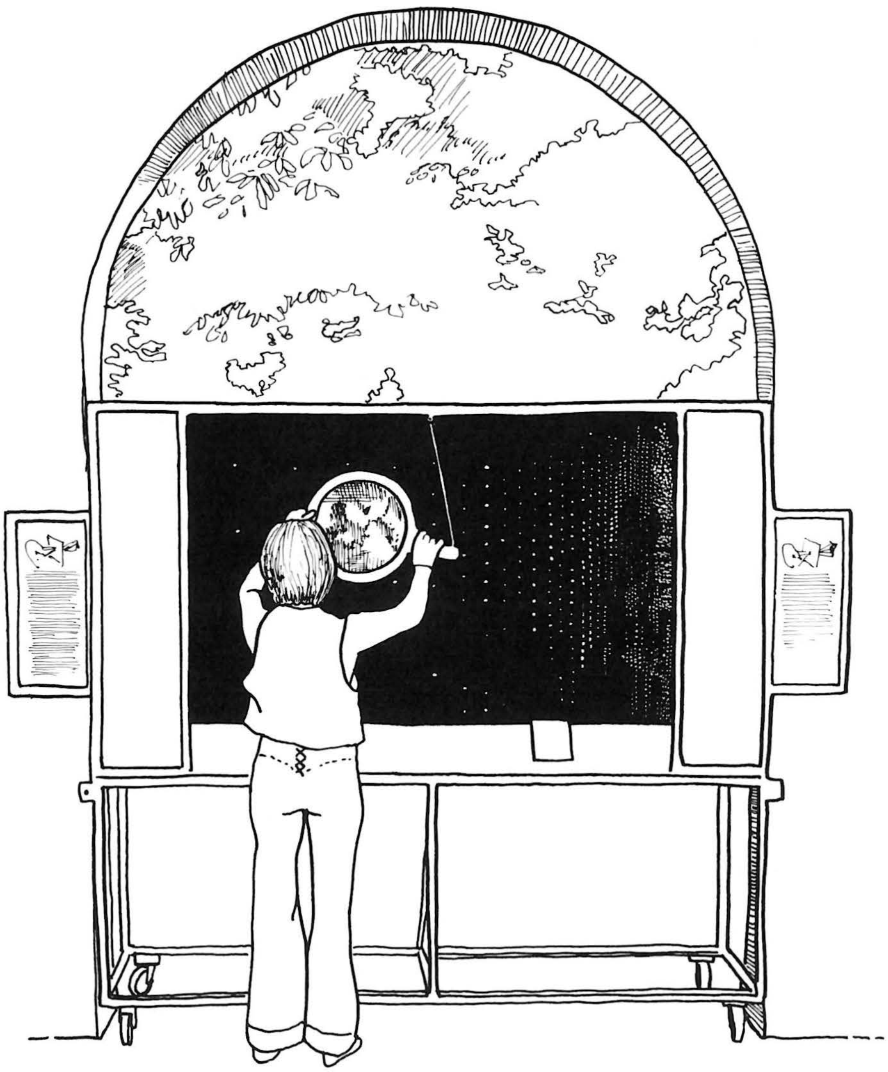
The exhibit must have explicit instructions (we have illustrations of someone ducking into the kaliedoscope, plus the name of the exhibit) which tell people to duck under the walls into the exhibit or else people tend to view the structure as a large wooden signboard. Even with graphics the exhibit sometimes goes unused for quite a while, even when the museum is crowded, until someone tries it and supplies an example that other people can follow. The exhibit is difficult for some people to get into since it requires a moderate amount of bending to get under the 40" high mirror (senior citizens especially experience this problem). Of course, the mirrors require periodic cleaning for best results.

Related Exploratorium Exhibits

REFLECTION

- **Look Into Infinity**
- **Shadow Kaleidoscope**
- **Corner Reflector**
- **Primary of a Cube**

Holes In A Wall

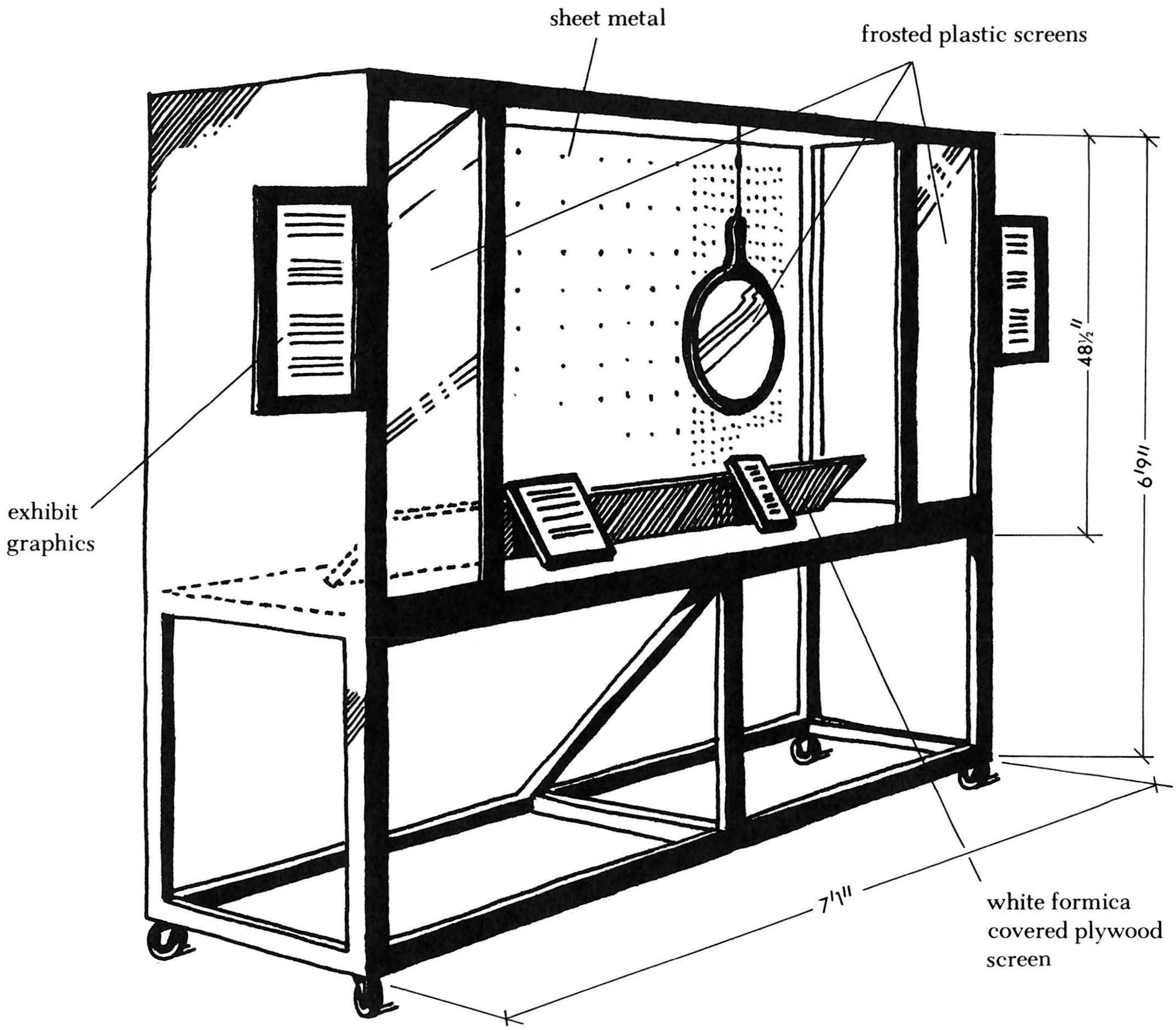


Description

Holes in a Wall is an outdoor exhibit (we keep it in the front entrance) which demonstrates that at every point in space there is an image of the scene beyond it. This phenomenon is shown with a large piece of sheet metal drilled with small holes, with very few holes at one end gradually increasing in number to a dense clustering at the other. The visitor holds a frosted plastic screen in front of the wall and observes that an image is formed by each and every hole in the screen with the images becoming very crowded and confused at the "holy" end of the exhibit even though each individual image remains sharp.

Construction

The exhibit is constructed inside of a frame made of 1" square steel tubing (with .062" wall thickness for strength



and ease of welding). The frame has wheels for mobility since we take the exhibit inside at night. Our frame is 85" wide and is designed to fit between the pillars in our entryway. A 48" tall box is mounted inside of the frame whose rear wall is drilled with holes. The first 24" of the rear wall was drilled by hand with a small drill (1/8") so the images would be sharp, the next 43" with a 3/16" drill, and the last 18" was made of predrilled sheet metal (3/16" holes) covered with black contact paper. Some locations in the contact paper were then punched through to reveal the holes. The inside of the box is painted flat black for light shielding which is necessary because the images are not very bright. Our entryway is a fairly dark area and ambient light makes the images difficult to see because they are dim. A white board (Formica covered plywood) runs along the entire length of the exhibit on the bottom of the box tilted at an

angle towards the holes to provide a continuous screen that shows smoothly the transformation from few to many overlapping images. The frosted plastic screen (12"in diameter) is made of "P/M vinyl," plane (shiny) on one side and matte (frosted) on the other. It is mounted in a wooden holder with a handle and hung from the top of the exhibit with a steel cable. A note on the paddle directs the user to hold the screen with the shiny side toward the holes to eliminate distracting reflections of the area behind him. The graphics are mounted on wings which stick out from the sides of the frame. Pins fit through holes in the frame to keep the exhibit in place between the pillars.

Critique and Speculation

The contact paper sometimes gets more holes poked in it. If the user learns something from doing this it is probably worth the effort of replacing the contact paper once in a while. The frosted screen tends to become unfrosted due to countless greasy fingerprints and it should be cleaned periodically.

Additions and Changes (1990)

For this exhibit to work, the side on which the visitor stands must be dark compared to the other side. We recently added a hood to our exhibit to ensure that the visitor's side would be in the dark.

Related Exploratorium Exhibits

IMAGE FORMATION

Lens Table
Sophisticated Shadows
Cracks in a Door
Jewels
Pinhole Magnifier
Pinhole Telescope

Exploratorium Exhibit Graphics

To do and notice:

Pick a single hole at the left which is near your eye level.

Hold the screen up against the hole, and notice the spot of white light. Then pull the screen toward you about a foot and notice that the spot of light becomes an upside-down image of the houses, etc.

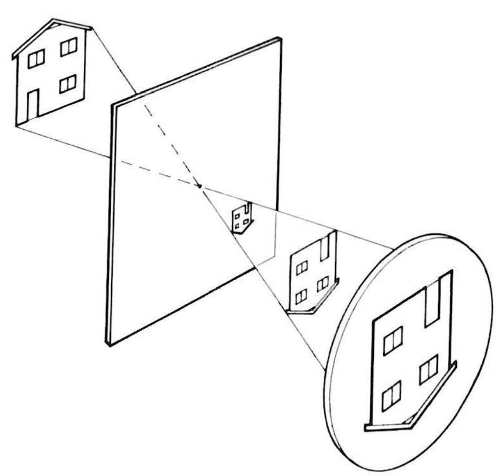
Move to the right with the screen. More holes mean more images. At the far right there are so many holes and images that you can no longer see any one image.

What is going on:

When the viewing screen is held up against the hole, all the light coming through the hole is in the spot of white light.

As you move the screen away from the hole the light coming from each part of the scene begins to separate and spread out so that an image becomes visible, i.e. the spot of light coming through the hole contains all the infor-

Each hole lets light reach the screen like this:



mation of the scene, but you cannot decode this information unless you move the screen away from the hole. As you do so, the image becomes more distinct but also dimmer.

When you move the screen to the right, more images are added, i.e. more information appears on the screen until at the far right so much information appears that the screen seems to contain no information.

Whenever you look at a white wall, you are looking at a mosaic of overlapping images. In fact the light all around is filled with information in the form of images. A wall with a hole in it acts like a filter- it blocks some images and lets some images pass. The pupils of our eyes are also such filters.

Analogously, the space around us is also filled with radio waves. If we heard them all at once there would be so much information we couldn't hear any one program. The tuning of the radio acts like a wall with a hole in it, blocking out most of the information so that we can hear some of it.

Not only a white wall but anything you look at is illuminated by a mosaic of images of whatever is around. For example, look at the sunlight on the ground that has filtered through tree leaves and you will see a mosaic of sun images. Look at your friends. You will be able to see them only because they are illuminated with images of you.

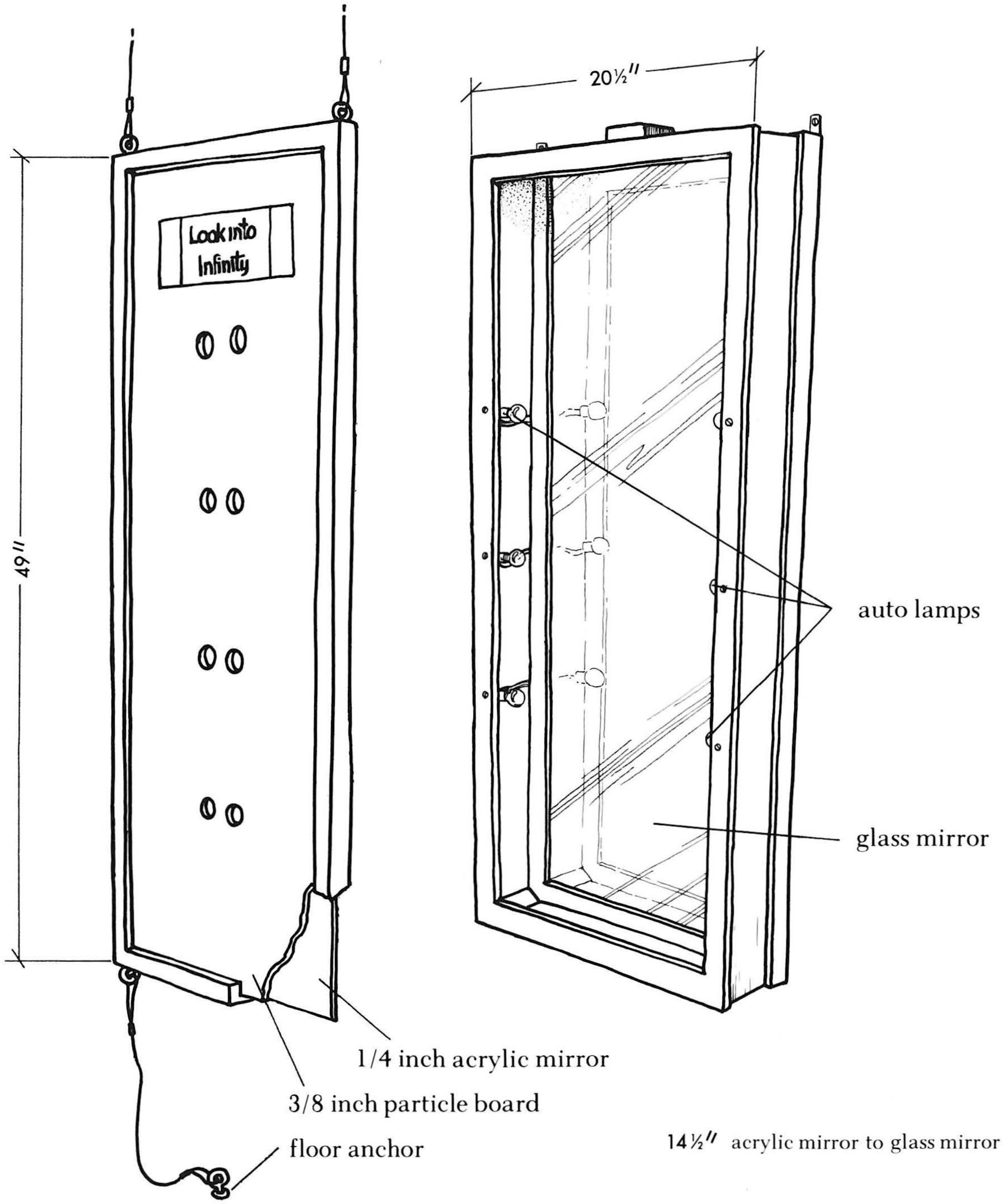
Look Into Infinity

Description

Look Into Infinity is a simple exhibit showing reflections and reflections of reflections, forming a tunnel stretching off into the distance. It consists off two parallel mirrors, one of which you can look through by means of eye holes drilled into it.

Construction

Two mirrors are used, one of 1/8" glass and the other of 1/4" acrylic in our version, hung parallel to each other about 1 foot apart. Acrylic was chosen for the freely hanging mirror because of its non-breakable qualities and its machinability. The mirrors measure about 18X48 inches. The glass mirror is hung permanently on the wall surrounded by a frame along the edge of which are mounted 6 low voltage auto tail-lamps. These lamps increase the distance (number of reflections) that the user is able to see. The plexiglass mirror is backed with 3/8" particle board and has a thin wooden frame around its edge to hold onto. It is hung from a height of 8 feet with steel cables. Four sets of eye holes are drilled into the mirror at various heights to accommodate all sizes of people from small children to adults.



Critique and Speculation

The only thing that we would add at this time are handles along the edge of the plexiglass mirror to make it more apparent that the mirror is supposed to be handled. The 1/4" plexiglass mirror could be replaced with an 1/8" thick mirror to reduce the thickness of plastic the light must pass through, and hence the amount of absorption.

Related Exploratorium Exhibits

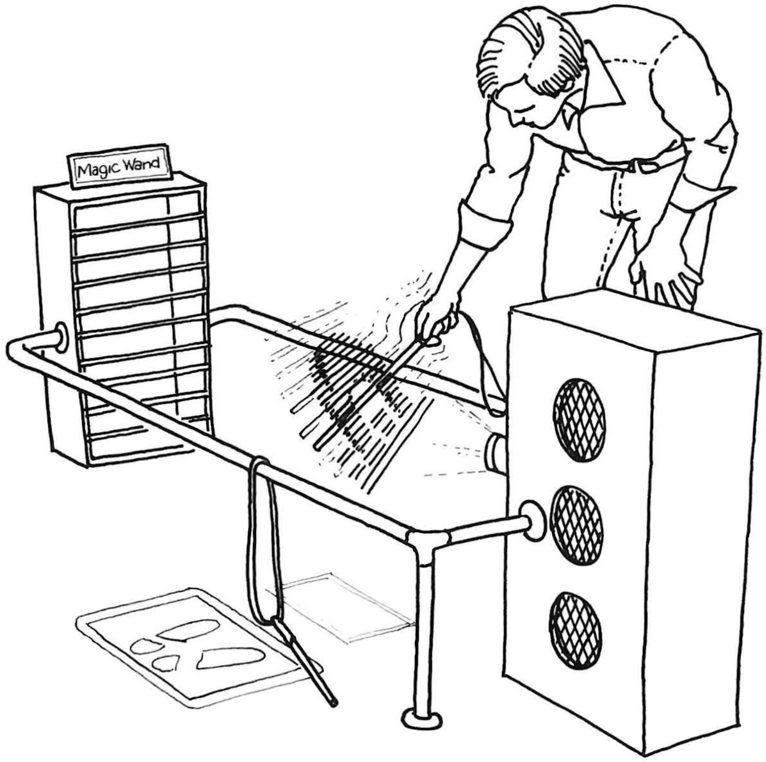
IMAGE FORMATION - MIRRORS

- **Duck Into Kaleidoscope**
- **Rear View**

REFLECTION

- **Corner Reflector**
- **Primary of a Cube**
- **Shadow Kaleidoscope**

Magic Wand



Description

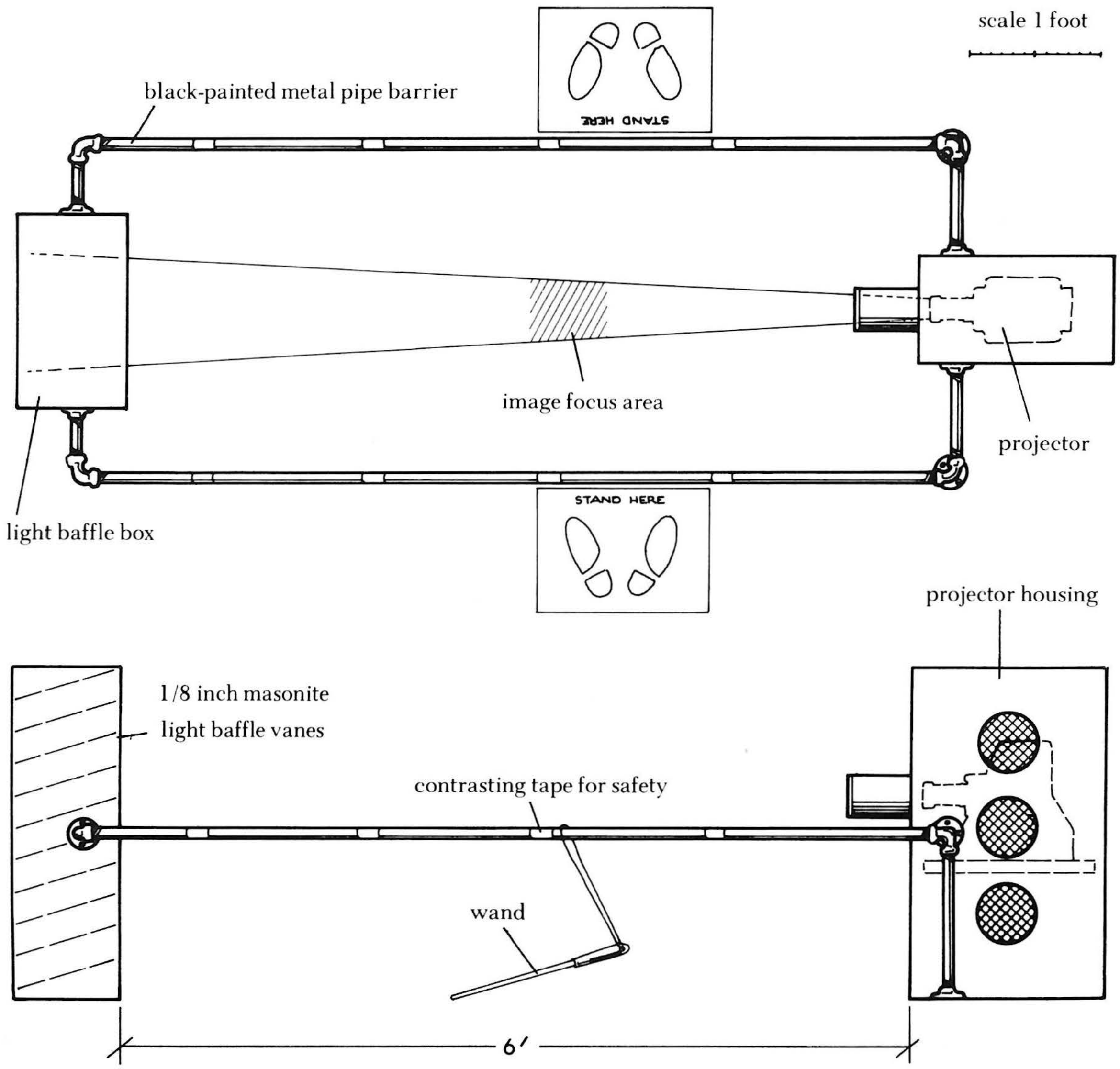
The visitor waves the "magic wand" rapidly up and down in an apparently dark area. A picture of the Palace of Fine Arts magically appears where the wand is waved. This exhibit works because of the persistence of vision in the eye/brain of the visitor.

Construction

The exhibit is very simple, consisting of a non-automatic slide projector and light baffle. The slide projector is focused midway between it and the baffle. Our projector has a built in cooling fan which is necessary since it is housed in a box and would otherwise overheat. It projects through a tube in front of the box which cuts down on the scattered light. The tube has a screen in it to keep the lens from being poked with the wand. The slide that is projected should be simple and of some recognizable object.

The wand is made of wooden doweling, 1/4" in diameter and about 12" long with a larger 1/2" dowel handle. The dowel is painted white for high reflectivity and must be kept clean since dark spots on the rod will cause streaks to appear across the picture when waved.

The wands are attached to the iron pipe barrier with nylon cord long enough to allow movement in and out of the focal plane. The barrier was constructed to keep people from walking through the projected image, and needs to be prom-



inently marked to keep people from tripping over it.

The baffle box at the end of the exhibit is painted flat black and has backward slanting wooden vanes inside of it to catch and absorb as much light as possible. This way, no clue is given of what will be seen when the wand is waved.

Additions and Changes (1990)

We no longer use wooden dowels, which tended to break and become a hazard. Instead, we use nylon rods covered with heat-shrink tubing. It is important that the wand be opaque and white. We use the heat-shrink tubing since nylon is translucent and yellowish.

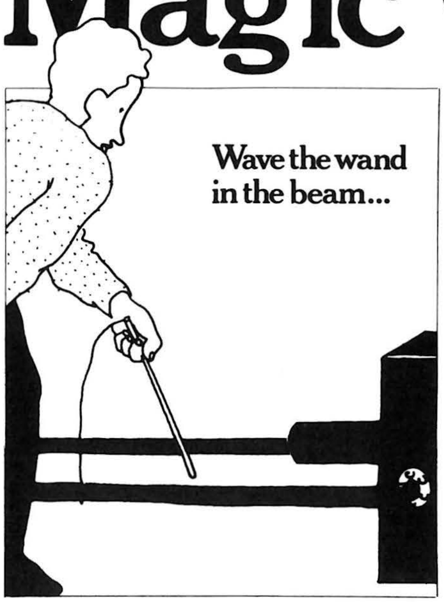
Related Exploratorium Exhibits

PERSISTENCE OF VISION

Whirling Watcher
Lightform
Persistence of Vision

LIGHT

Magic Wand



Wave the wand
in the beam...

To do and notice:

○ Stand on the footprints.

○ Hold the stick in your left hand and wave it rapidly up and down between the railings. Lean over and look at the front of the stick.

What is going on:

The beam of light from a slide projector is focusing an image of a slide in the empty space between the railings. The image is there even when you aren't waving the wand, but you can't see it unless something reflects the light to your eyes.

When you wave the wand, the image reflects piece by piece from the moving wand. Your eye retains each of these pieces for about one-tenth of a second—long enough to let you put them together and make a composite picture.

for left side of exhibit

Magic Wand

To do and notice:

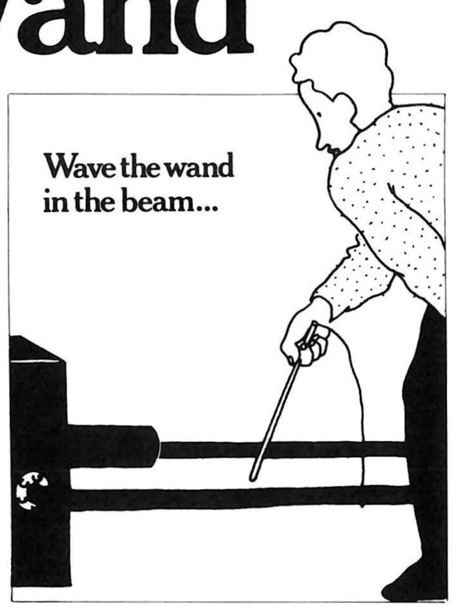
○ Stand on the footprints.

○ Hold the stick in your right hand and wave it rapidly up and down between the railings. Lean over and look at the front of the stick.

What is going on:

The beam of light from a slide projector is focusing an image of a slide in the empty space between the railings. The image is there even when you aren't waving the wand, but you can't see it unless something reflects the light to your eyes.

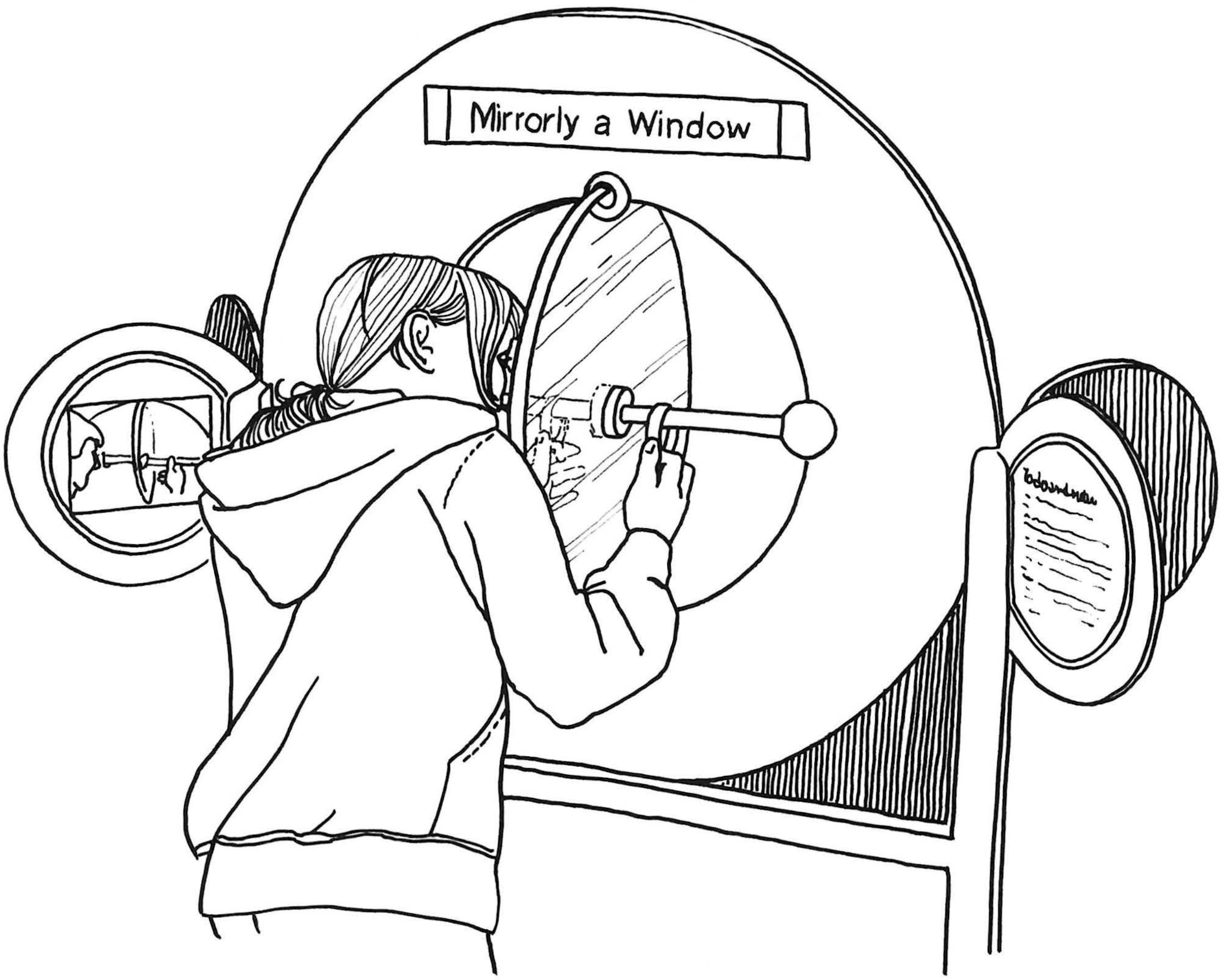
When you wave the wand, the image reflects piece by piece from the moving wand. Your eye retains each of these pieces for about one-tenth of a second—long enough to let you put them together and make a composite picture.



Wave the wand
in the beam...

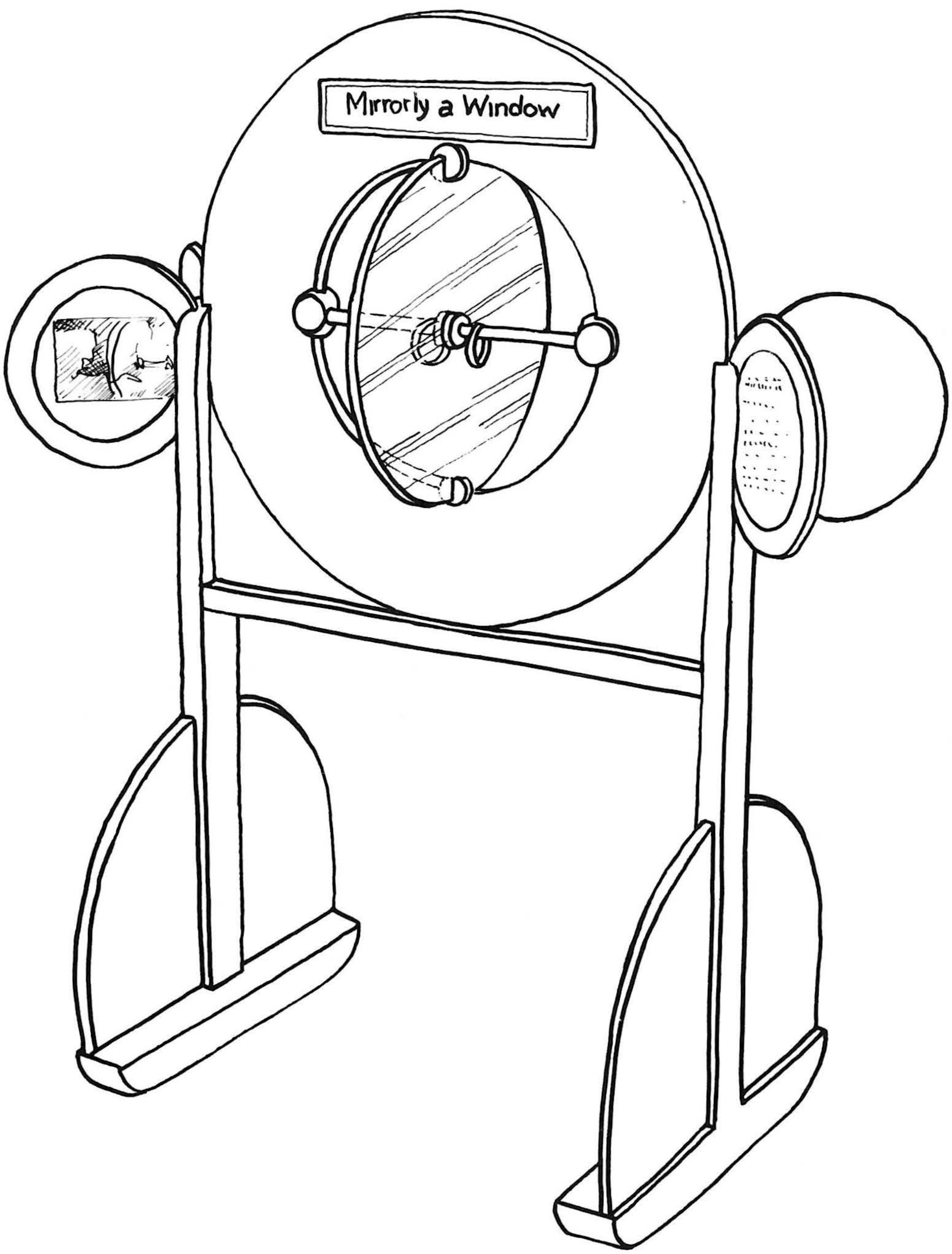
for right side of exhibit

Mirrorly A Window



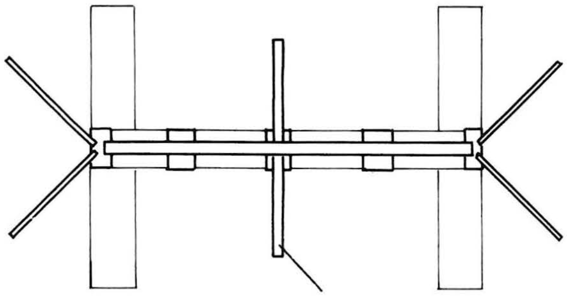
Description

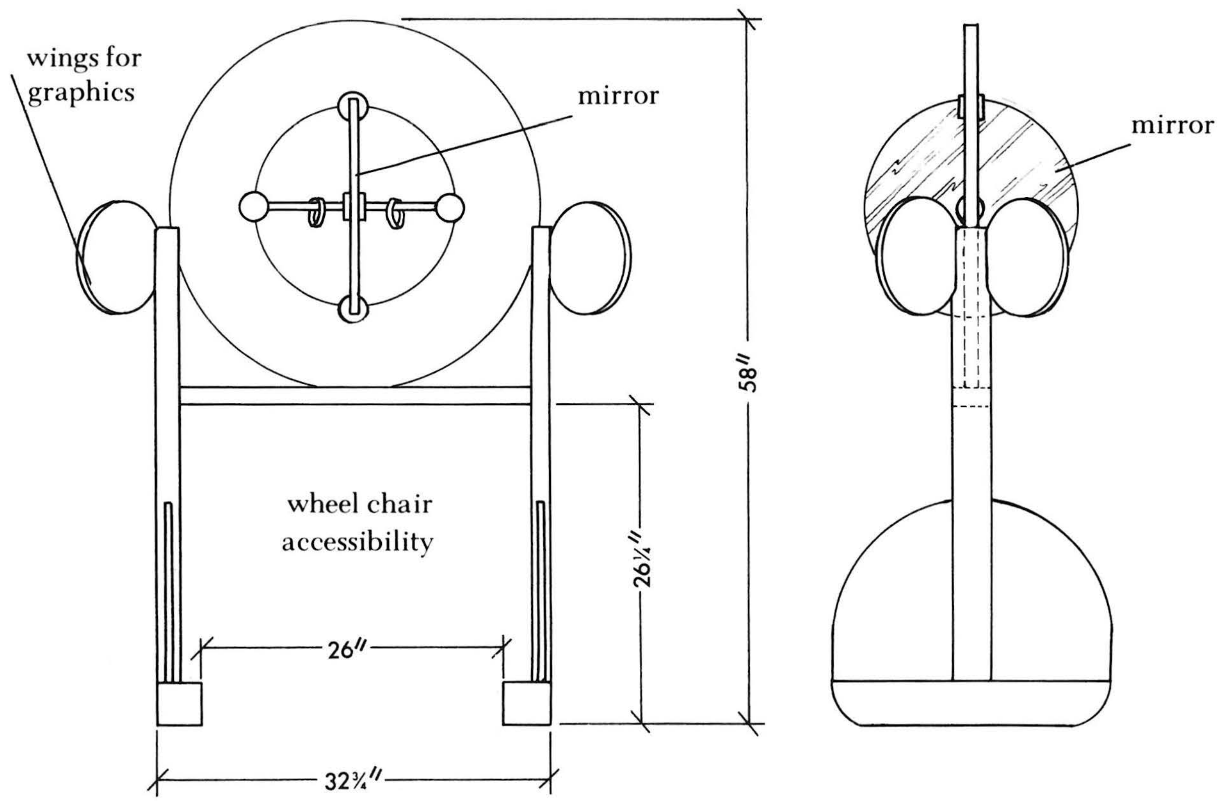
This exhibit demonstrates hand-eye rivalry by letting the brain "see" a scene which is contradicted by what it feels through the muscles of the body. This is done with a mirror which looks like a window because of the symmetrical exhibit built around it. A plastic rod appears to run through the mirror with two rings hanging on it. When the visitor places the rings equidistant from the double-sided mirror and looks into one side while trying to grasp the ring with the hand on the other side of the mirror, a strange sensation is felt. It is as if the hand is not cooperating with the brain since only the reflection of the hand which is <u>not</u> trying to grab the ring is seen.



Construction

To work properly, the exhibit must be built symmetrically around the mirror, both front to back and right to left, so that the reflections of the exhibit in the mirror make it appear as though the mirror is actually a piece of glass and you are just looking through it at the other parts of the exhibit on the far side of the glass. The mirrors in our version are 2 disks of mirrored





plexiglass 1/4" thick, cut into circles and placed back to back. Two plexiglass rods (3/4" diam.) run from the side of the exhibit and are held in depressions in the mirror (see illustration). Two plastic rings (2.5" diam.) hang on the rods. The stand which holds the mirror and graphics is constructed with plywood. Any design for the stand will work as long as it is symmetrical about the mirror. Our stand was designed with wheelchair accessibility in mind as well as ease of use by both children and adults.

Additions and Changes (1990)

Placement of this exhibit is critical. It should be placed so that there are no reflections that provide clues that the visitor is looking into a mirror. For the same reason, the lighting should be balanced so that it is even on both sides of the exhibit.

Related Exploratorium Exhibits

HAND EYE COORDINATION

Reverse Distance
Thread the Needle
Touch the Spring

To do and notice:

Stand directly in front of the exhibit.

Hold the rings with the thumb and forefinger of each hand.

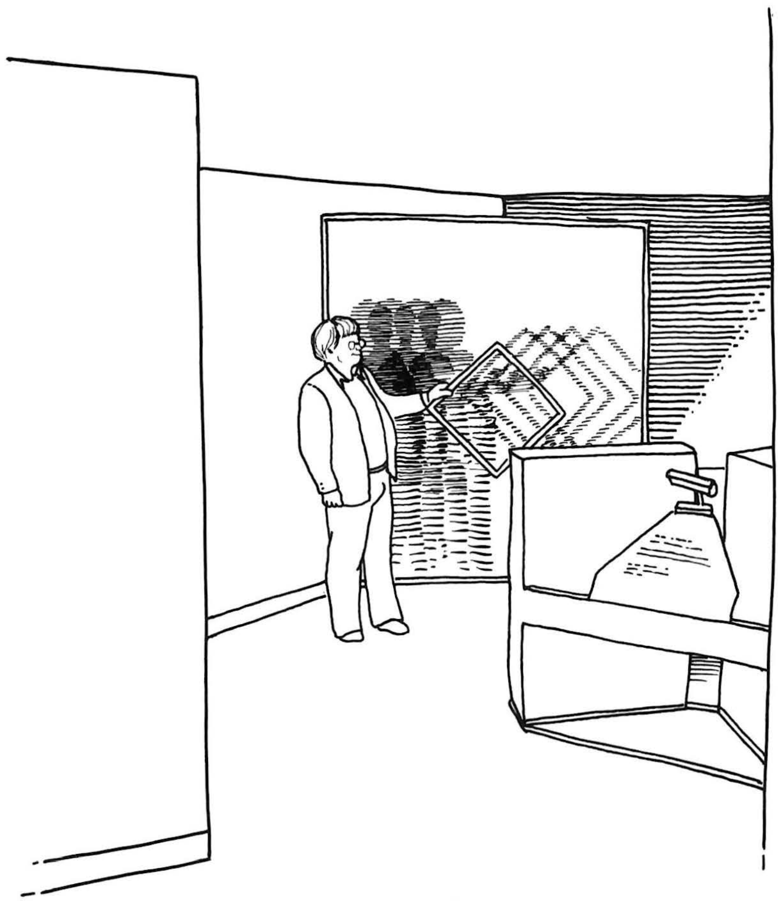
Lean to the left side and look through the "mirror window" at your right hand.

Now move only the ring in your right hand.

The strange sensation that you get is the consequence of the importance of hand eye coordination or feedback.

* A photograph is also included in the graphics which shows someone using the exhibit.

Sophisticated Shadows

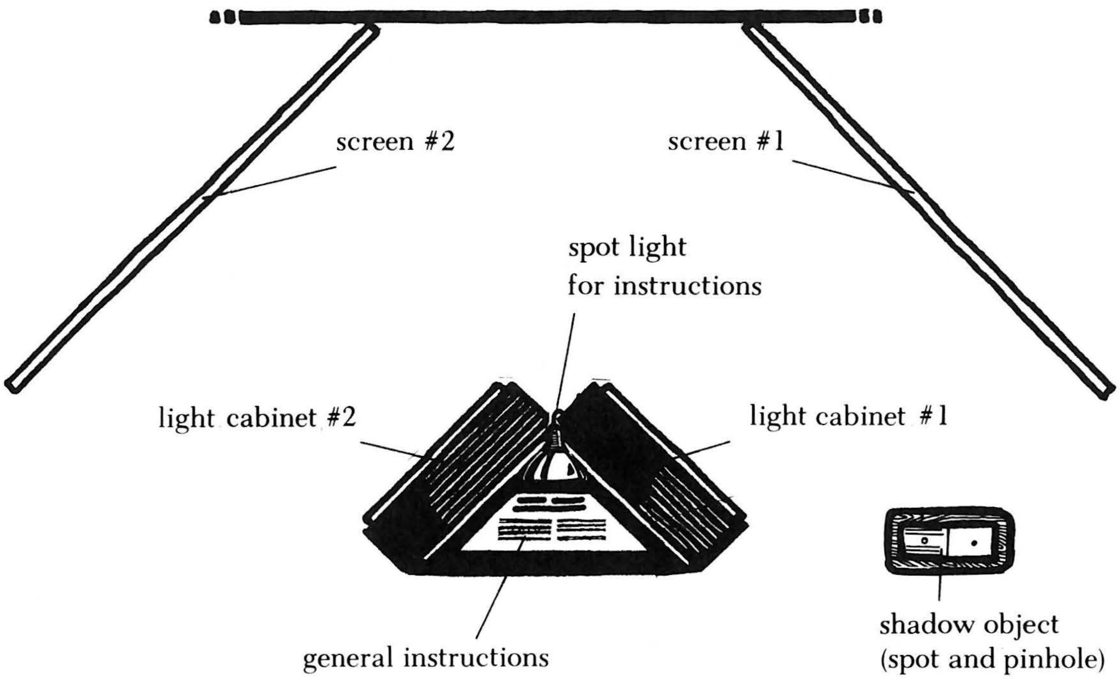


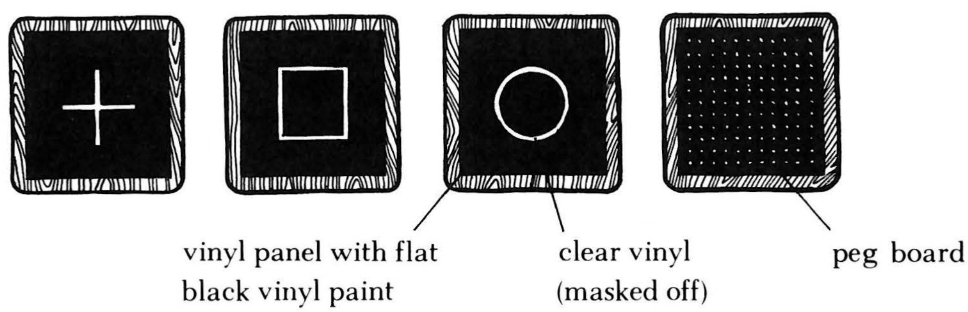
Description

Using a variety of differently shaped light sources, the visitors can experiment with the formation of shadows using their own bodies or one of the several objects supplied in the exhibit. The light sources each have on/off switches so they may be used separately or in conjunction with each other.

Construction

This exhibit, built in a darkened room, is divided into two sections, each with its own 6x7 foot screen and several different types of light sources. The sections are pointed at right angles to each other to prevent the light of one from interfering with the other. One section has as its light source a row of nineteen 12 volt auto lamps, closely spaced (1" apart), 34" above the floor. A switch allows the user to turn off every other lamp, leaving 9 bulbs lit. The light source in the other section has 4 individually switched and different sources; horizontally and vertically mounted F8T5/CW fluorescent bulbs, a 150 watt incandescent bulb mounted base down, and another incandescent mounted head on with a dark spot in the center (top) of the bulb. The light sources are enclosed in their own boxes, made of particle board, with





removable tops and glass windows in front. The shadow objects are:

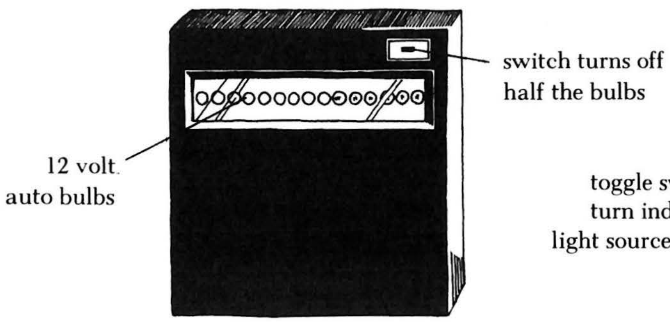
1) Single pinhole and single spot
2) Squares made of layers of masonite
3) Rings " " " " "
4) Pluses " " " " "
5) Clear squares and black background
6) " rings " " "
7) " pluses " " "
8) Pegboard

The clear pinholes, squares, rings, and pluses are masked onto clear 1/16" vinyl panels with tape and then painted with flat black vinyl paint and the masking later removed leaving clear areas (see illustration). This black paint is the type used for silk screening and may have to be thinned with the appropriate thinner to obtain a brushable mixture.

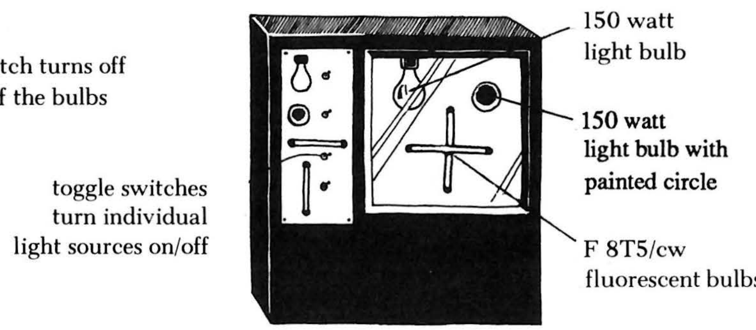
Critique and Speculation

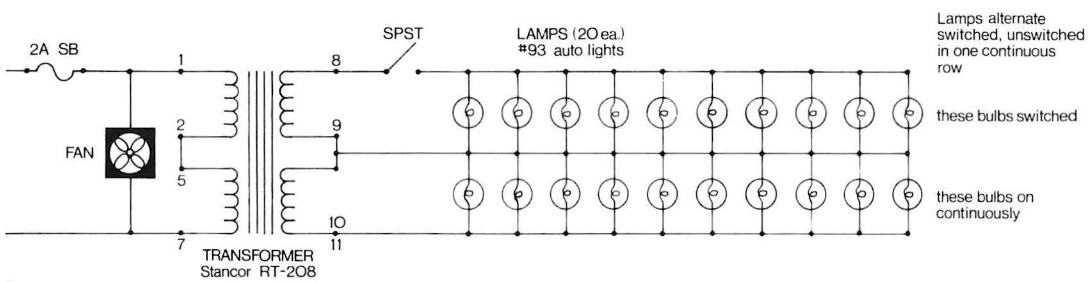
The area the exhibit operates in must be kept very dark. External lights must be kept to a minimum (a small doorway helps) or extra shadows will be cast. Because of this darkness, the switches on our light source boxes are virtually impossible to see. Illuminated switches (dim) would help greatly.

cabinet #2

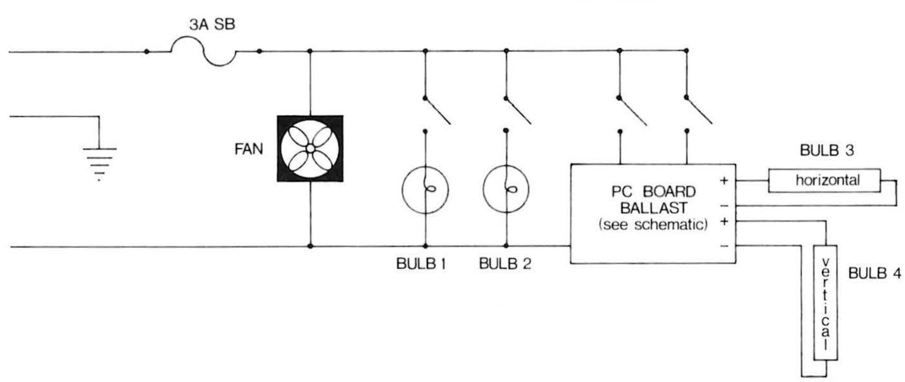


cabinet #1





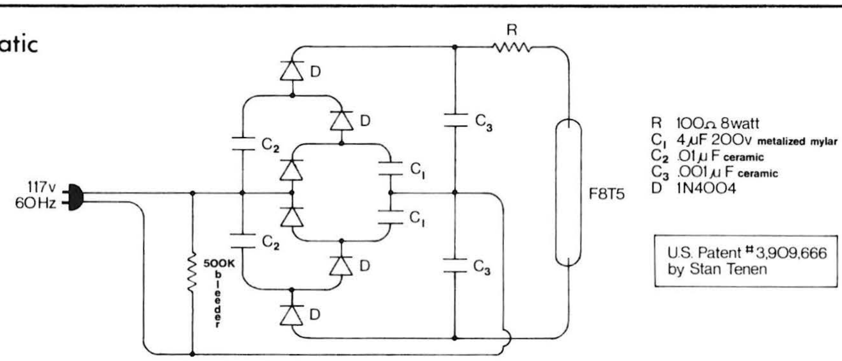
cabinet #2



cabinet #1

ballast circuit schematic

(2 required)



R 100Ω 8watt
C_1 4µF 200v metalized mylar
C_2 .01µ F ceramic
C_3 .001µ F ceramic
D 1N4004

U.S. Patent #3,909,666
by Stan Tenen

cabinet #1

Related Exploratorium Exhibits

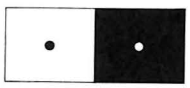
IMAGE FORMATION
- **Lens Table**
- **Holes In a Wall**

LATERAL INHIBITION
- **Gray Step 1—Horse's Tail**
- **Gray Step 2—Rotating Gray Step**
- **Gray Step 3—Mondrian**

SHADOWS
- **Colored Shadows**
- **Shadow Box**
- **3-D Shadows**

Exploratorium Exhibit Graphics

Find a small panel that looks like this:



and follow the suggestions printed on the panel.

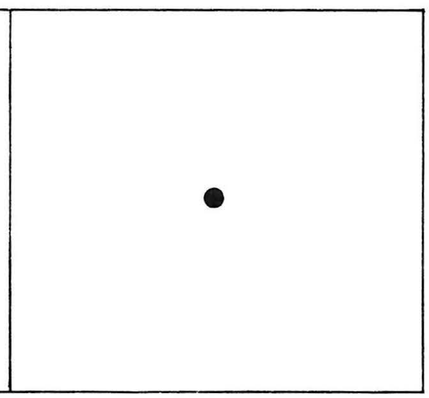
Also make shadows with your hands and body and the various objects on the rack.

To do and notice: 1

Turn on only the two crossed fluorescent tubes.
Hold this panel a foot or two in front of wall 1.
Notice the image of the crossed tubes in the dark section of the panel's shadow.
Cover and uncover the hole in the panel with your finger.
Notice the black spot on the clear section of this panel and the shape of the shadow it makes on the wall.

○

Move the panel back and forth toward the wall.
Try the other lights by themselves and in various combinations.
Turn on only the horizontal tube. While you hold this panel, have a friend pass a hand back and forth in front of the horizontal fluorescent tube, or use the flat stick. Notice the effect on the light and dark images of the tube that you see on the wall.
Try the other panels by themselves and in various combinations.

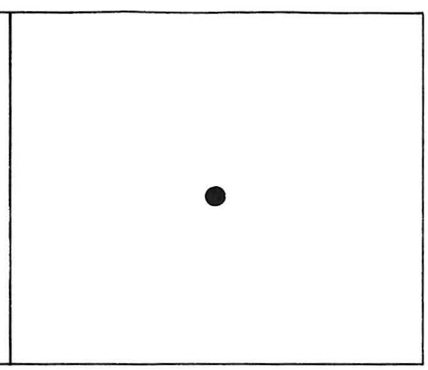


To do and notice: 2

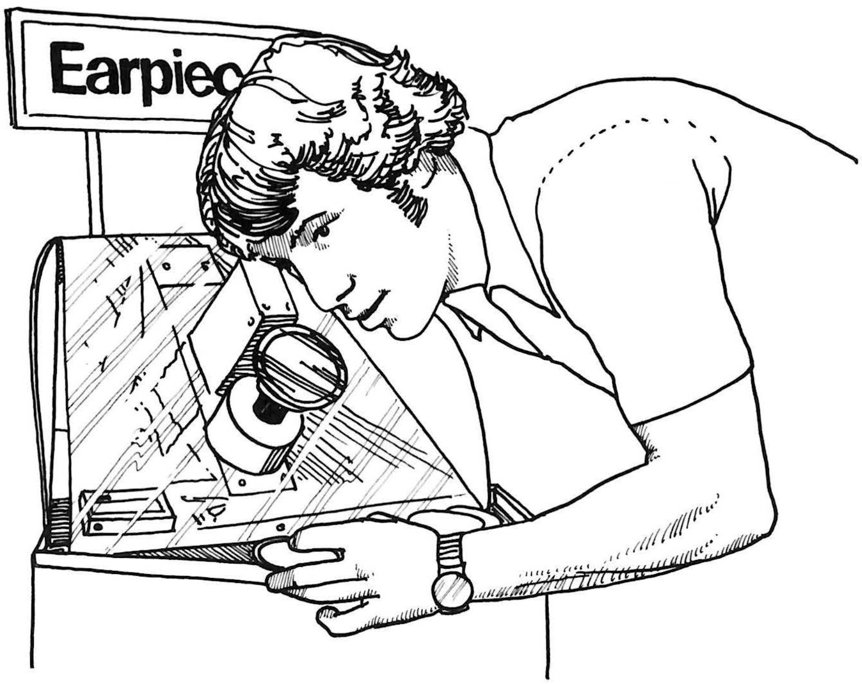
Hold this panel a foot or two in front of wall 2.
Notice the image of the row of lights in,the dark section of the panel's shadow.
Cover and uncover the hole in the panel with your finger.
Notice the black spot on the clear section of this panel and the shape of the shadow it makes on the wall.

○

Move the panel back and forth toward the wall.
Flick the switch to try more or fewer lights.
While you hold this panel, have a friend pass a hand back and forth in front of the lights, or use the flat stick. Notice the effect on the light and dark images of the row of lights.
Try the other panels by themselves and in various combinations.



Ear Piece



Description

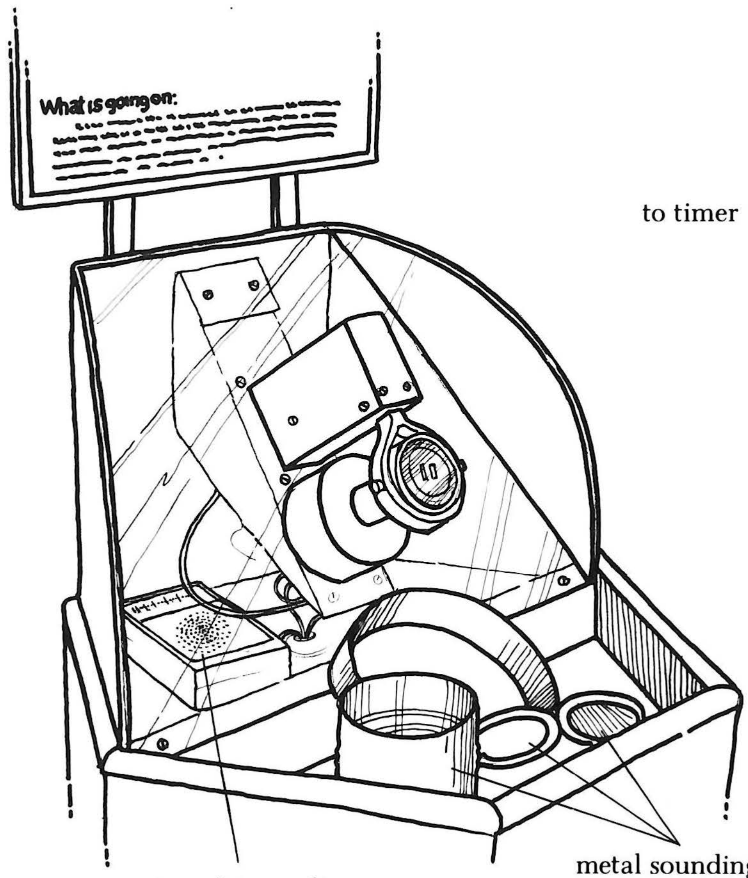
Ear Piece uses an old-fashioned telephone receiver (the type that had a separate mouthpiece) to demonstrate one way in which electric current can be turned into sound. The visitor walks up to a silent exhibit with the earpiece sticking out of the top. One of many available metal disks or cans is then selected and placed on the earpiece. The metal vibrates from the magnetic fields produced by the current in the earpiece and produces sound. The source of the sound (a transistor radio) is clearly seen through the plastic top of the exhibit.

Construction

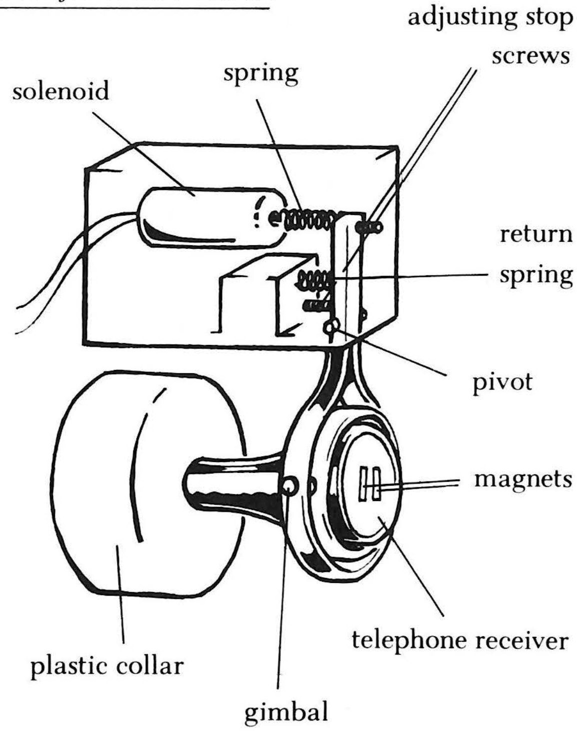
The exhibit is simple in construction. The earpiece is held in a polyethylene plastic collar at an angle to the table. The top of the earpiece has been removed and the magnet and coils are potted with clear potting compound to reveal what is inside the device while protecting it from abuse.

A selection of "sounding disks" is supplied in a bin in front of and below the earpiece for the visitor to place on the end of the earpiece. The sounding disks take the form of small steel food cans, film cans, mason jar lids, and anything which will stick to the magnet in the receiver.

Since the sounding disks stick to the magnet in the earpiece and we want the exhibit to be quiet when approached by the visitor, a rather elaborate device to eject the disk every minute was added to the exhibit. This is a solenoid activated lever and ring assembly placed



detail of ejector mechanism



around the periphery of the earpiece (see diagram) which is pulsed every minute to pop the disk off of the magnet and allow it to fall into the storage bin below.

Additions and Changes (1990)

We had some difficulty initially with lids that would stick to the magnet despite the ejection device. We've found since that if the lids are light enough, they fall off without any problem. Subsequently, we removed the ejection device from the exhibit, deciding that it was more trouble than it was worth.

We also include some aluminum disks that will not stick to the magnet. With these, the visitor can demonstrate that the disk must stick to the magnet to produce sound. Because aluminum lids are difficult or impossible to find, we cut our own disks from sheets of aluminum.

Exploratorium Exhibit Graphics

To do and notice:

Put one of the metal pieces onto the circle of the ear piece. Notice that only metals which are attracted to a magnet make a sound.

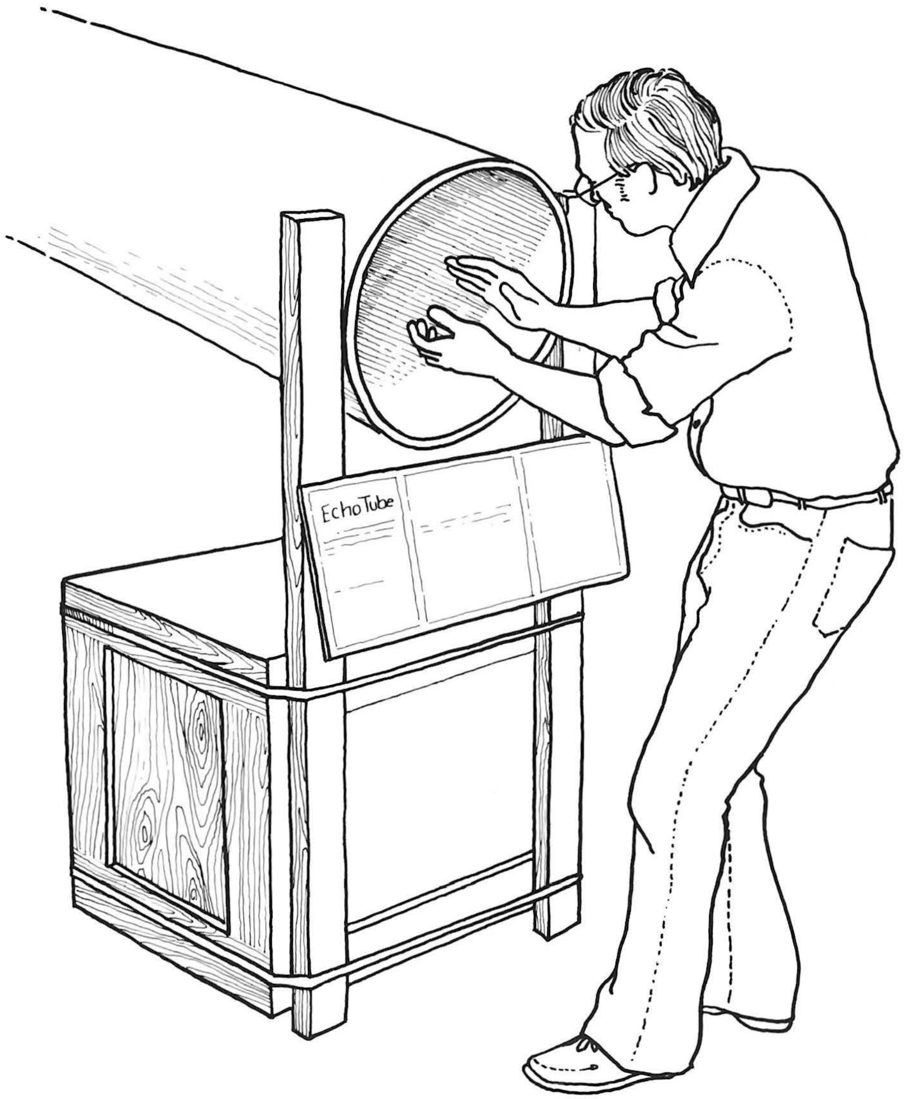
Note: The exhibit has a device that automatically knocks off the metal which makes a sound so that it will be silent for the next visitor.

Until very recently if you unscrewed the cap of the ear piece of a telephone you would have found a metal plate and a small electromagnet identical to this ear piece. Modern telephones work the same way, but you can no longer take them apart without destroying them.

What is going on:

The vibrating electric currents which come into your house over the telephone wires run through the coils of a small electromagnet in the ear piece of the telephone. These vibrating currents produce a push-pull magnetic field which causes a thin iron plate to vibrate, which causes the air to vibrate, which causes your ear drum to vibrate and eventually stimulates the nerves of your inner ear.

Echo Tube

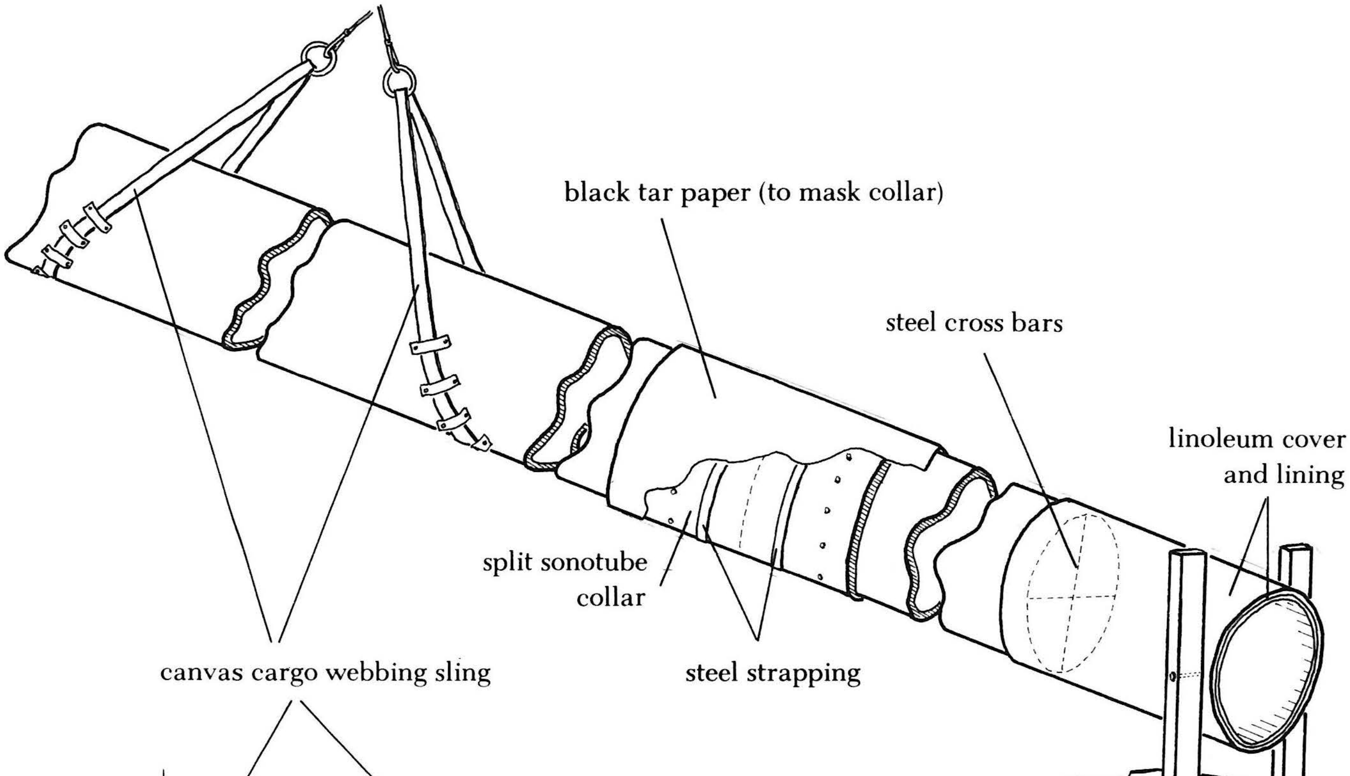


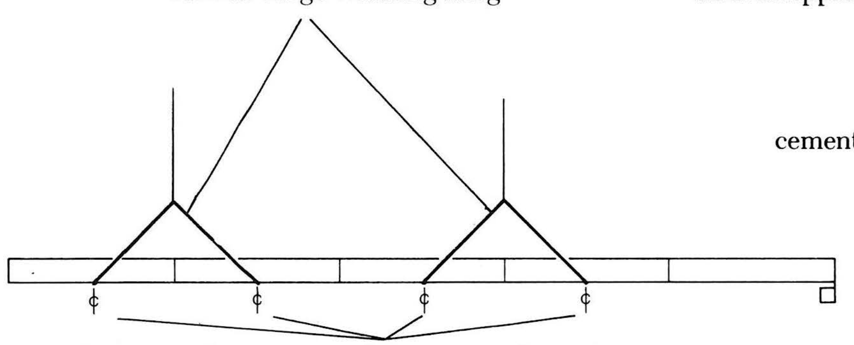
Description

The Echo Tube is a very long cardboard tube sloping up almost to the roof of the Exploratorium. When the visitor claps his hands at the end near the floor, an echo is heard about 1/5 second later. The echo has a strange sound unlike the original clap (and much like the ricochet heard in old cowboy movies) due to the many different paths that the sound takes inside the tube. A rough estimate of the speed of sound can be made by timing the echo of the clap. You can also listen to the echo of your voice as it traverses the length of the tube. This makes speaking difficult due to the delay between saying a word and hearing it (we have another exhibit demonstrating this effect called Delayed Speech).

Construction

The echo tube is made from 5 twenty foot sections of cardboard cement form tube (also called "sonotube") 18" ID





adjoining tubes supported at centers of gravity

with 1/2" wall thickness. The total length of the tube is therefore 100 feet (the larger the diameter of the tube, the better the bass response of the system will be; larger tubing is however heavier and more expensive). Each section of the sonotube is supported near its center of gravity with a canvas strap sling hung from the ceiling. The sling is bolted through the wall of the tube to prevent slippage. This method of suspension prevents twisting at the joints of each section which would tend to distort the tube. The sections are put together with a split sonotube collar which is first glued into place and then bolted through with large washers to distribute the load to the tube walls. We had to hire one of our smaller explainers to crawl into the tube to fasten the washers and nuts. Steel straps such as those found on crates were then wrapped around the collars to add further strength. The tube is closed at the upper end with a piece of plexiglas® which has a cross taped on it to show the endcap in place to the user. Our tube is hung at an angle of approximately 20 degrees to the floor so that exhibits may be placed

under it. This places the top of the tube some 35 feet above the ground. If you don't have a high roof such as ours, we believe that it is possible to have the tube bent around a 50 foot radius without affecting the quality of the sound. Since the tube is made of cardboard we have wrapped linoleum around the outside and inside of the lower 4 feet of the tube to protect it. Also, since children would love to climb up through the 100 feet of tube, we have found it necessary to place thin 1/4" steel bars through the tube 4 feet from the lower end. The lower end is attached to a heavy box which keeps it from being swung.

Critique and Speculation

The upper end of the tube is very hard to dust.

Exploratorium Exhibit Graphics

To do and notice:

Clap into the tube and listen to the sound when it returns. The returning sound does not sound like the original clap, but rather like a long drawn-out whine beginning with a high frequency and ending with a lower one.

Notice that it takes about 1/5th of a second for the sound to return.

You can also stick your head into the tube and listen to the echo of your voice.

What is going on:

When you clap into the tube, you create a disturbance in the air that is shaped like the surface of a sphere. This disturbance spreads out at the speed of sound in air (about 1080 feet per second). Diagram 1 shows a two dimensional picture of the disturbance. Not all parts of this wave disturbance will land on the ear at the end of the tube. The part traveling along the axis of the tube will land on the ear. The next part that will hit the ear is the part directed so that it bounces off the side of the tube half way down. The part that bounces one fourth of the way down will also hit the ear, as will the part that bounces 1/6, 1/8, 1/10 of the way, etc. The more bounces the wave makes the longer is the path over which it travels in getting to the ear and the longer it takes to get to the ear. Diagram 2 shows the first four paths of the sound wave that will reach the ear.

If we stretch out these jagged paths into straight lines, diagram 3, the length of these lines will equal the total distance which those parts of the wave must travel to get to the ear. Each path is longer than the one before, and what starts out as one sharp sound becomes a succession of sounds.

Diagram 4 shows the succession of pulses traversing the tube. Note that the pulses are close together at the beginning of the sound but gradually become spread out. When the pulses are close together you hear a high frequency; when they are far apart you hear a low frequency.

In these diagrams, the hands and the ear are shown at opposite ends of the tube just to make the drawings less cluttered. The Echo Tube works in the same way, only the waves are reflected at one end so that you can hear the sound of your clap.

Related Exploratorium Exhibits

REFLECTION

Wave Machine
Organ Pipe

exhibit graphics continued

Diagram 1

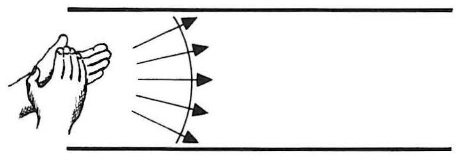


Diagram 2

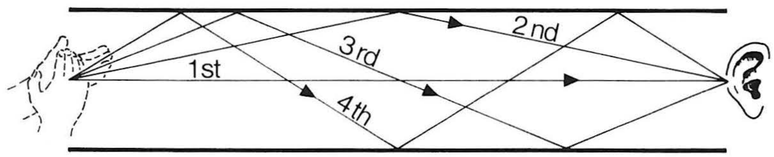


Diagram 3

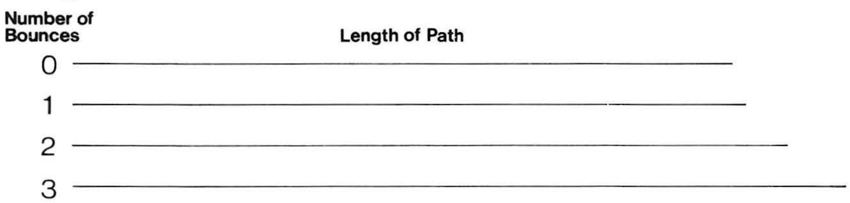
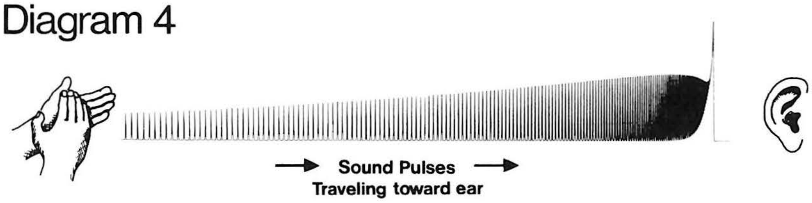
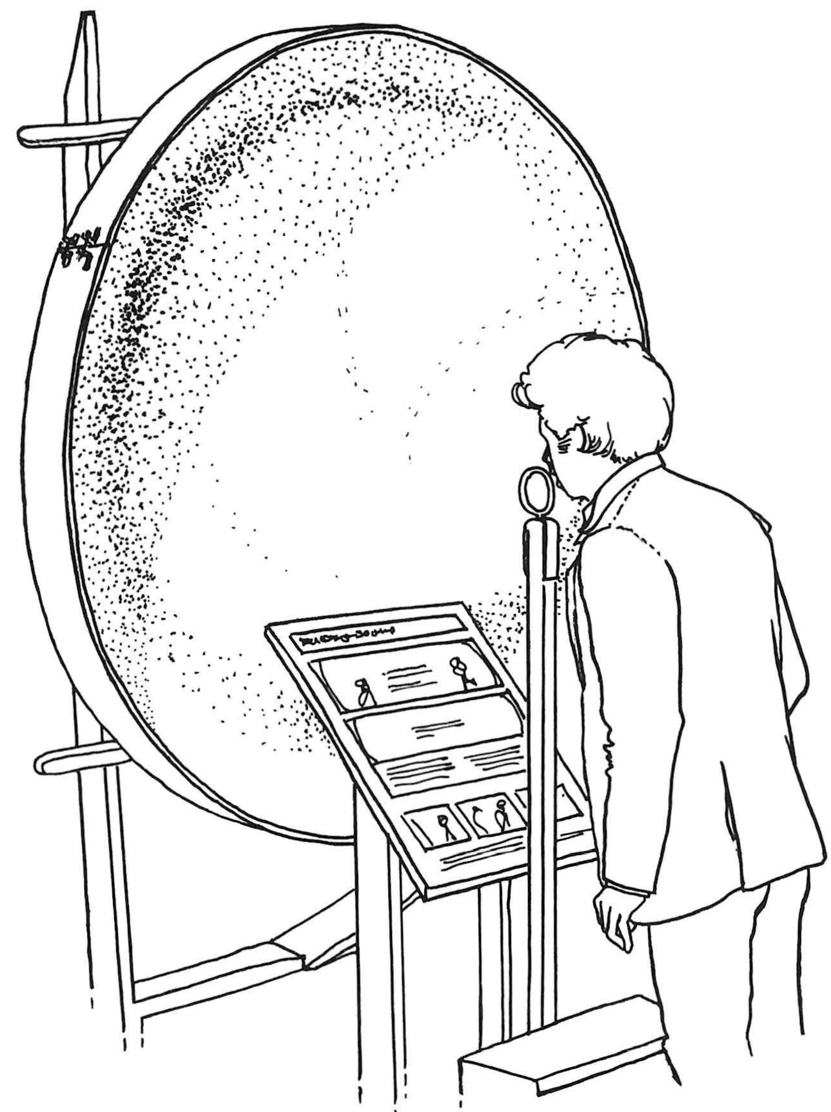


Diagram 4



Focused Sound

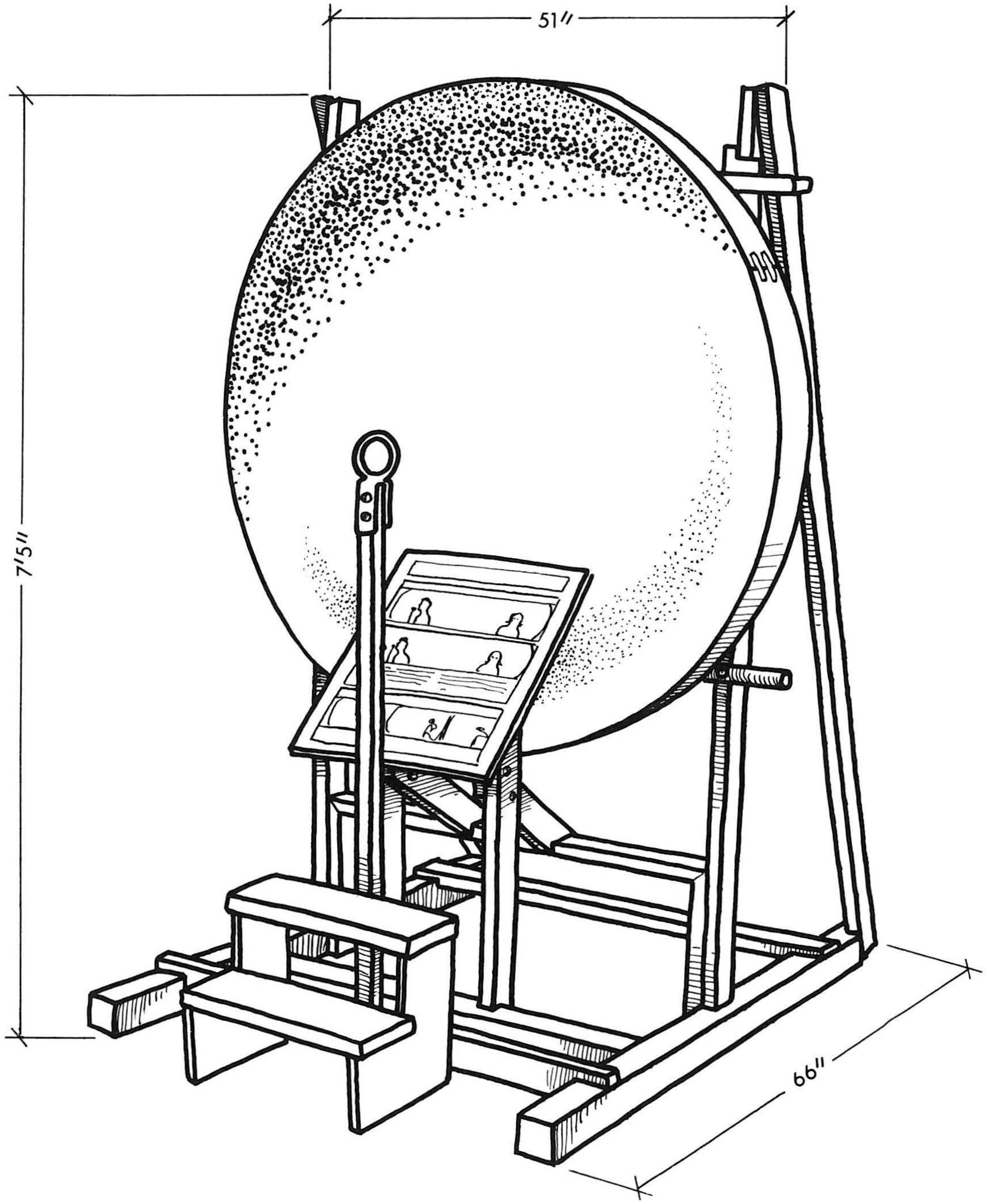


Description

This exhibit demonstrates the reflection and focusing of sound by two large spherical reflectors. The two reflectors are large plaster "mirrors" facing one another approximately 50 feet apart. When a person at one mirror talks (or even whispers when the museum is quiet) a person at the other mirror can hear him.

Construction

Our sound mirrors were made by professional statuary builders during a renovation of the Palace of Fine Arts. They first made a negative casting of a large spherical metal searchlight mirror 5 feet in diameter with a 2 foot focal length (used in our "Hot Spot" exhibit). This negative casting was then used as the mold for the two plaster sound mir-



rors. A masonite ring is bent around the circumference of the mirror and fastened with bolts and nuts to keep the edge of the mirror from being chipped. The mirrors were mounted on a wide base (to keep the mirrors from being pushed over) made of 2x4's and 4x4's. The visitor speaks and listens at the focal point, which is located by a welded steel ring held up by a post. We found it necessary to put some steps up to the ring so that children could use the exhibit without being lifted.

Critique and Speculation

The plaster mirrors work very well but due to the rarity of finding the sculptors and searchlight mirrors to start with, we don't recommend our approach at building this exhibit.

Rather, we recommend finding a surplus pair of dish antennas such as those used for microwave communications or radar. We have seen these quite regularly in governmental excess property bulletins and this equipment can usually be purchased fairly cheaply. The dishes do not have to be the same size or focal length as long as they are accurately pointed at one another and the speaking-listening rings are accurately placed at their respective foci. These commercial dishes are made of both metal and fiberglass, both of which would hold up well and could be used as an outdoor exhibit.

Additions and Changes (1990)

Unfortunately, this exhibit is not wheelchair accessible.

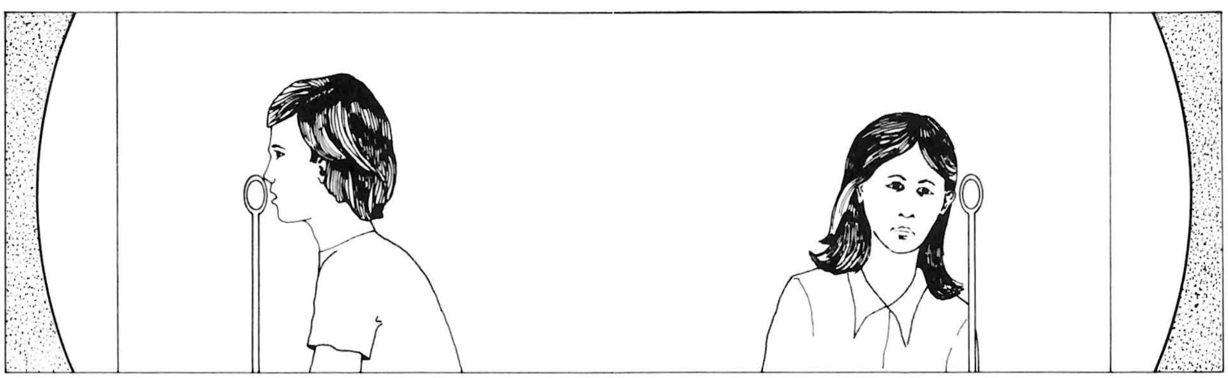
Related Exploratorium Exhibits

Conversation Piece
Hot Spot
Water Waves

Exploratorium Exhibit Graphics

The graphics consist of a series of things to try accompanied by several illustrations.

Speak to someone else



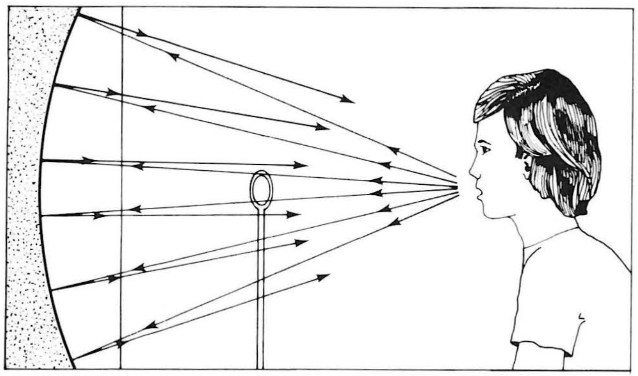
Talk directly into the green ring while a friend listens at the other ring.

If you are alone, ask a red- jacketed explainer to be your friend.

The sound waves travel from your mouth to the plaster mirror, there they are reflected toward the other mirror.

Your friend hears you clearly because her mirror focuses the sound onto her green ring. IT IS THE SPECIAL PARABOLIC SHAPE OF THE MIRROR THAT FOCUSES THE SOUND IN THIS WAY.

If you stand between the mirrors you can eavesdrop on someone's conversation.

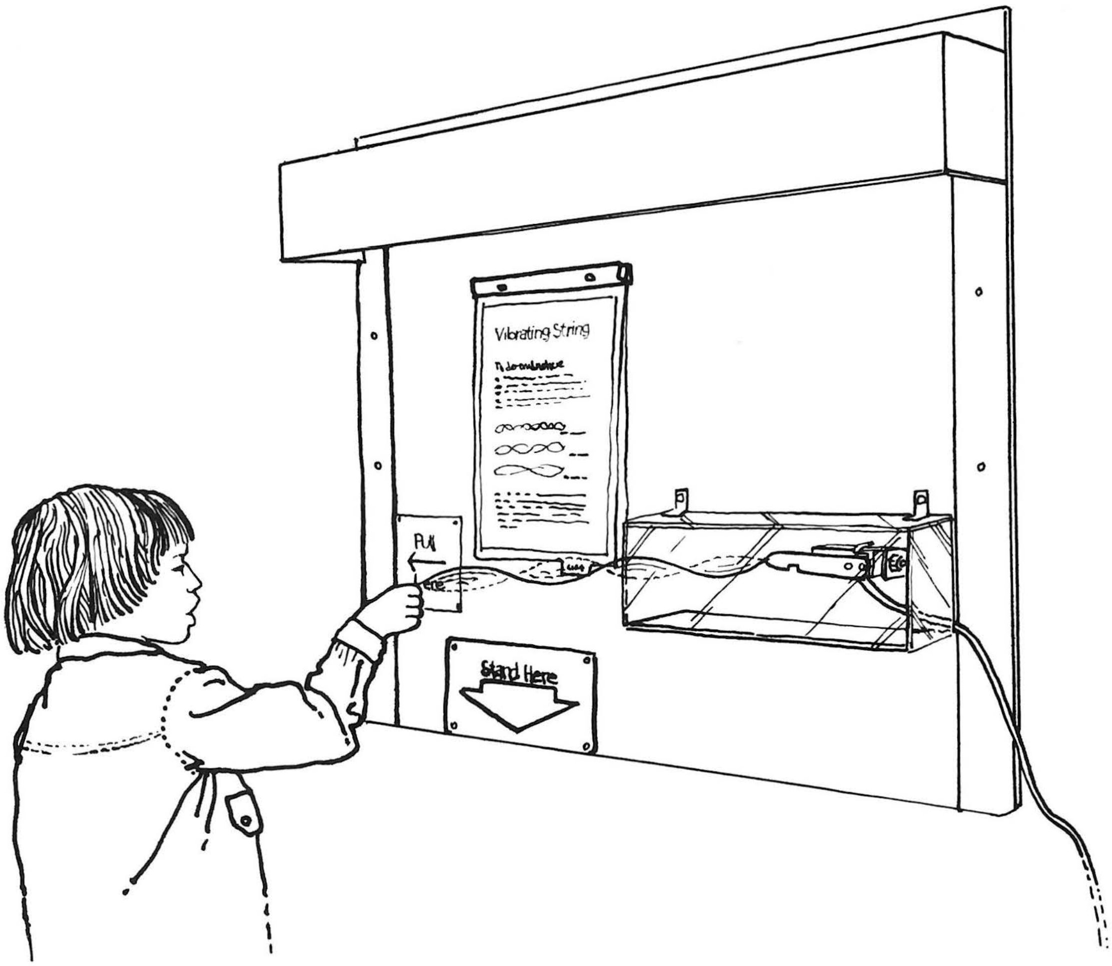


Move back about two feet so that the ring is half way between you and the mirror.

When you speak the sound waves are now reflected back to your own ears.

A flat wall does not focus back all the sound.

Vibrating String



Description

A solenoid vibrates a piece of nylon fishing string held at one end by the user. Standing waves are set up in the string and nodes and antinodes appear. If the tension on the string is changed, the number of nodes and antinodes can be varied.

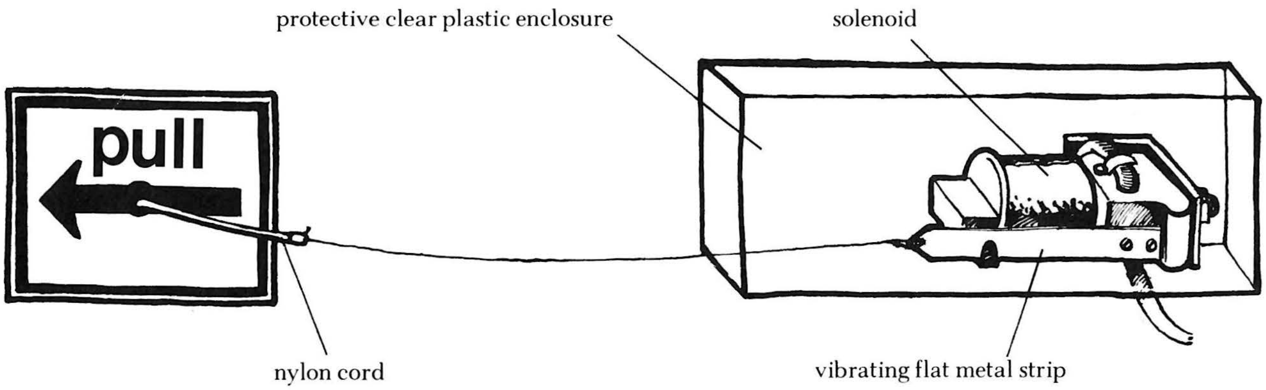
Construction

The solenoid vibrator is a piece of demonstration equipment available from:

Sargent Welch
1617 East Ball Road
Anaheim, Calif. 92803

Order #3256A String Vibrator, 120 Hz.

The string vibrator is mounted on a vertical surface with a fluorescent lamp over it for illumination. The vibrator is partially enclosed in a plastic box since it has 120 volts on its coils. Heavy nylon fishing line is used as the string for its durability. The end of the string is tied to the backboard with a short piece of nylon cord.



Additions and Changes (1990)

We added a board where a person could rest his or her hand while holding the string. This lets the visitor have better control of the tension in the string. We now use white nylon string, instead of fishing line.

When we build new versions of this exhibit, we use a solenoid coil (ASCO 27-462-1) from:

The Automatic Switch Company
50-69 Hanover Rd.
Florham Park, NJ 07932
tel: (201) 966-2000.

Related Exploratorium Exhibits

WAVES, STANDING

Aeolian Harp
Bells
Giant Guitar String
Kettledrum
Organ Pipe
Piano Strings
Wave Machine

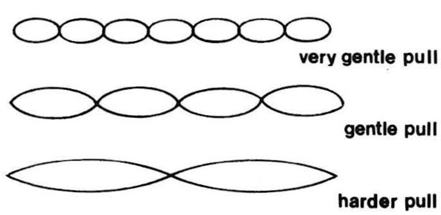
Exploratorium Exhibit Graphics

To do and notice:

Stand on mat to turn on the vibrator.

Increase the tension on the string by pulling gently and gradually harder to the left.

Notice that the shape of the vibrating string changes like this:



Hold the string near the vibrator with two fingers, and with a constant pressure gradually move your hand to the left. Notice that at certain positions of your fingers along the string, the string takes a vibration form similar to the drawing.

What is going on:

The metal strip to which the string is attached on the right hand end is moved back and forth 120 times per second by an electromagnet.

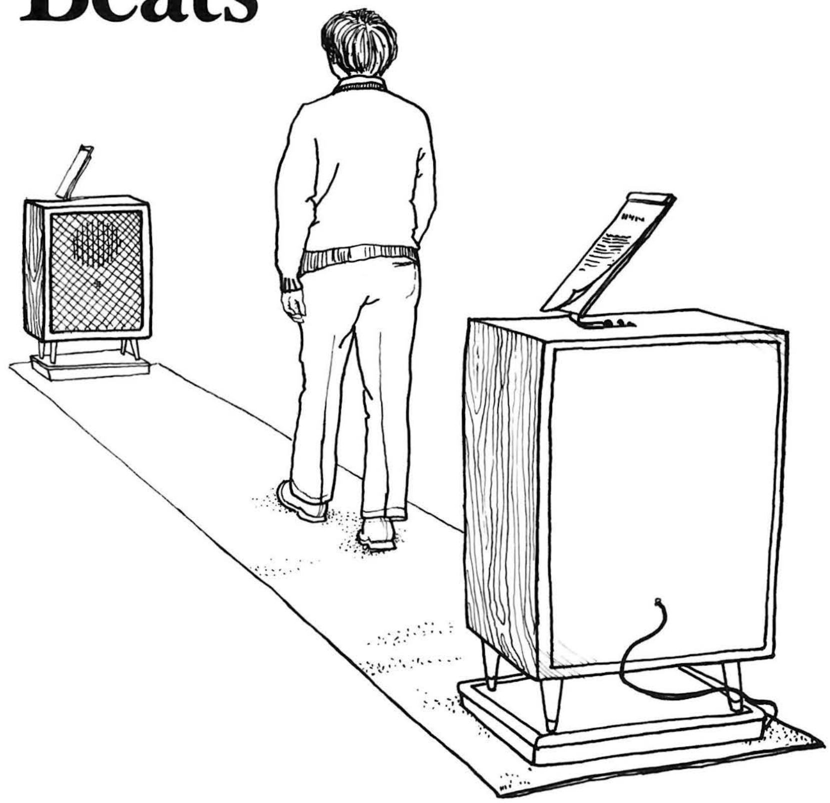
The vibrations which start at the right end of the string move along the string. The speed with which they move along the string increases when you pull harder on the string. The faster they move the longer the length of the wave in the string.

The waves are reflected back in the opposite direction when they reach the point where your fingers are holding the string.

The waves going out along the string and the reflected waves coming back combine to make a large motion of the string at some places and cancel each other at other places called "nodes".

Recipe No. 117

Walking Beats



Description

The doppler effect is dramatically demonstrated at very slow (walking) velocities. The person walks between two loudspeakers which are producing notes which are slightly different (by 1 Hz). The "envelope" of the sound can be made to increase or decrease in frequency by walking toward one or the other of the speakers.

Construction

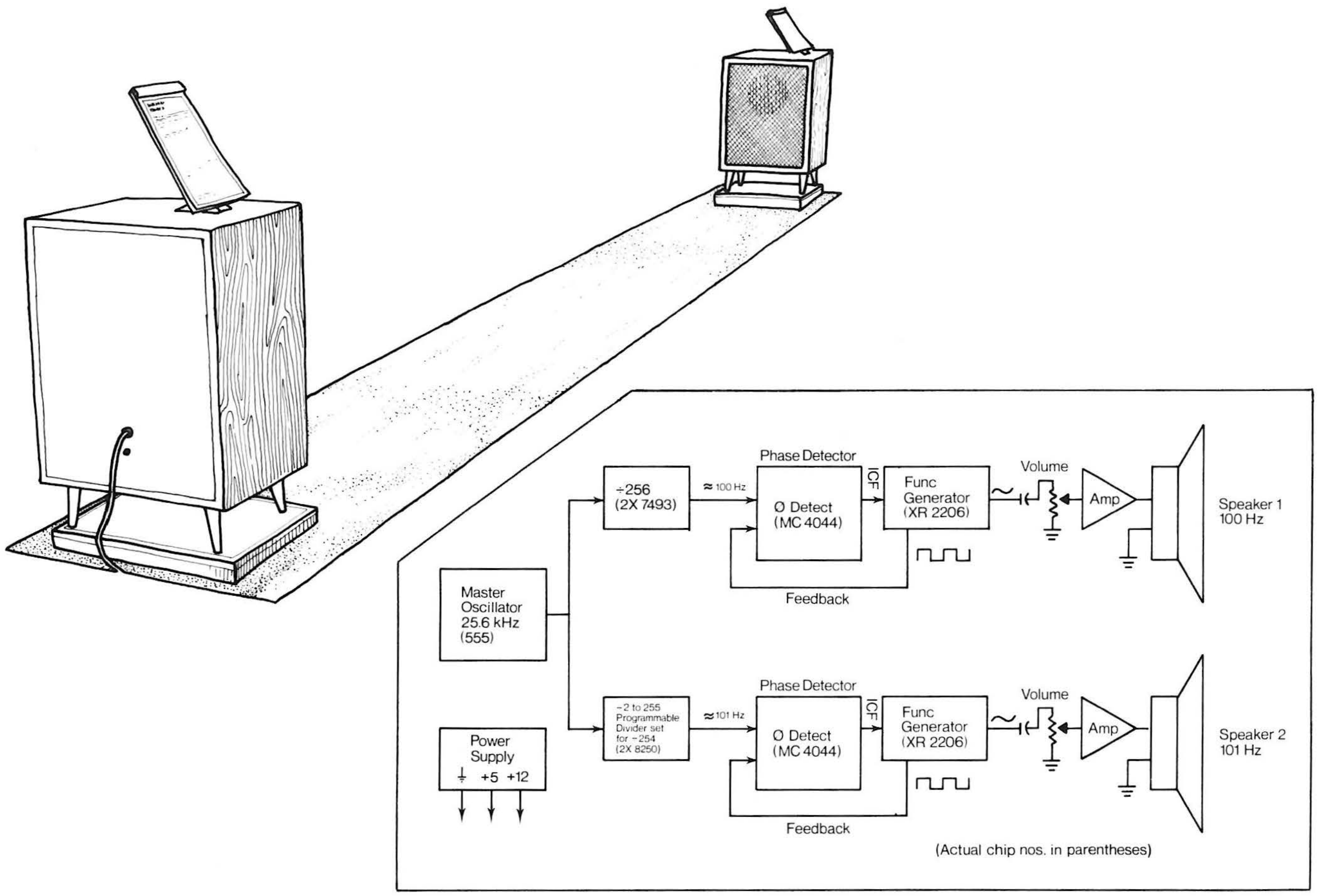
Two large 12" 8 ohm loudspeakers in bass reflex enclosures are pointed towards each other with a carpet runner between them. The speakers are powered by separate amplifiers to which are supplied the waveforms, one at 100 Hz and the other at 101Hz. The circuit is given in block diagram form below with the specific components used. They can be assembled on a perforated board, wire wrapped, or circuit boarded.

Critique and Speculation

This exhibit makes a low droning sound which gets lost in the Exploratorium environment. If the exhibit is placed in a quiet place the droning, at its usual volume, could become annoying to people exposed to it for extended periods. We use a key switch to turn down the volume of the speakers if the environment is quiet.

We have added a "frequency match" button to one of the speakers. When this button is pressed, both speakers play the same frequency. This button is useful for showing nodes and antinodes as well as demonstrating the wavelength of sound.

All that is needed is a time-delay relay which is triggered by the button on one of the speakers. This relay connects both of the speakers to the same signal.



Additions and Changes (1990)

For teaching purposes, we have added two buttons to our exhibit. One button shuts off one of the speakers for a short period of time. The other has both speakers produce the same tone for 15 seconds.

Related Exploratorium Exhibits

BEATS, SPATIAL AND TEMPORAL

Moiré Patterns
Picket Fence Beats

Exploratorium Exhibit Graphics

To do and notice:

Stand still between the two speakers and you will hear a low note, (i.e. a kind of wow, wow). These fluctuations in loudness are called "beats".

Walk briskly from speaker 1 to 2. The beats, the fluctuations in loudness, will occur more rapidly than when you are standing still.

Walk briskly from speaker 2 to 1. The beats will occur less rapidly than when you are standing still. In fact you may not hear any beats.

This exhibit was conceived on the Sausalito Ferry while walking back and forth between the exhaust stacks of the two engines.

What is going on:

The beats occur because the two speakers send out slightly different notes, one having 100 vibrations per second and the other having 101 vibrations per second.

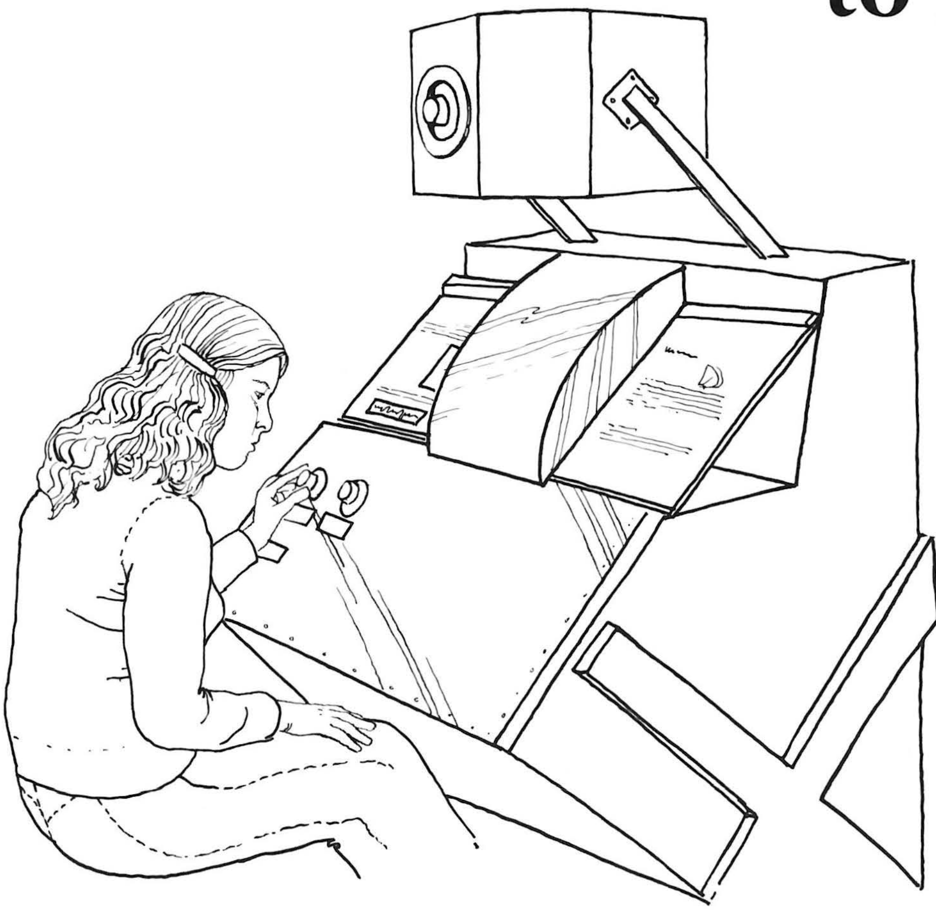
The sound waves from the two speakers both affect your ears. When the two waves are in step with each other they both push on your ear drum and work together to make a loud sound. Because they have different frequencies or tones they will get out of step 1/2 a second later. One wave will then push on your ear drum and the other will pull on your ear drum, and the sound will get softer because each wave cancels the effect of the other.

When you walk toward one speaker and away from the other you are moving into one set of pulses and waves and therefore meet them more often than when you are standing still. At the same time you are walking along with the sounds of the other speaker, the pulses of the waves do not hit your ear drums as frequently as when you are standing still. Hence you hear a slightly lower tone from the other speaker. The waves therefore get in and out of step more or less rapidly depending on which way you walk.

Can you decide which speaker is emitting 100 vibrations per second and which speaker the 101 vibrations per second?

The change in frequency when either the source or the listener is moving is called the Doppler Effect.

Crayfish Eye's Response to Light

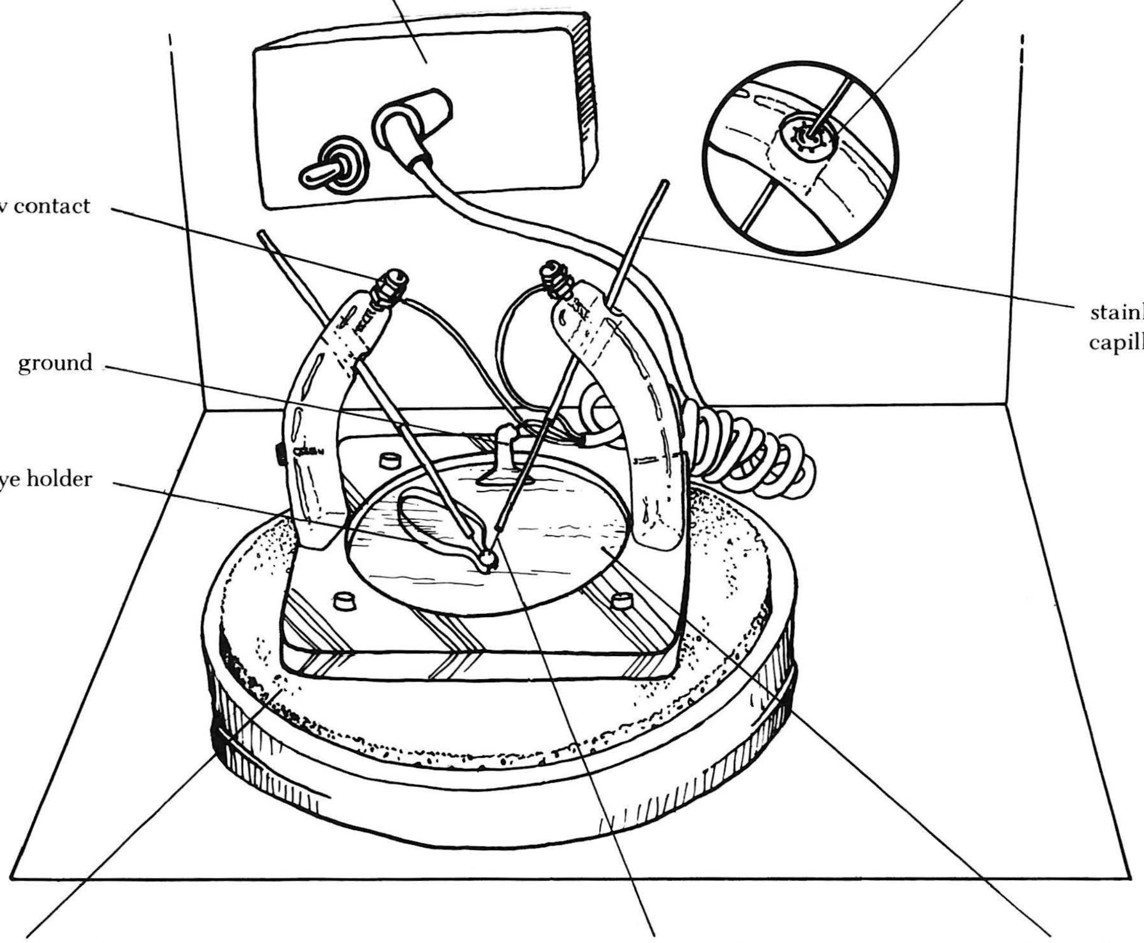


Description

The eye of a crayfish is removed and electrodes are implanted in it so that the electrical response of the eye to various forms of stimulation by light can be examined. Response to a continuous source of white light, a strobe light (variable frequency) with flashes equally spaced, and pairs of flashes (time between flashes in a pair can be adjusted) can be observed. With these variables, flicker fusion can be easily demonstrated. Flicker fusion allows us to see a movie (24 flashes per second) as a continuous flow of events.

Construction

The eye must be removed from the crayfish by cutting at the base of the eye-stalk with a sharp scalpel. Before this, the crayfish should be killed humanely by quickly inserting a sharp scalpel (no. 11 blade) between the eyes along the dorsal neural axis (we also use the crayfish tail for another Exploratorium exhibit; Muscle Stretch). After removal from the crayfish, the eye is held in a stainless steel "eye holder" bent out of a thin strip of sheet metal. The eye must be kept in a solution of Van Harveld's Crayfish



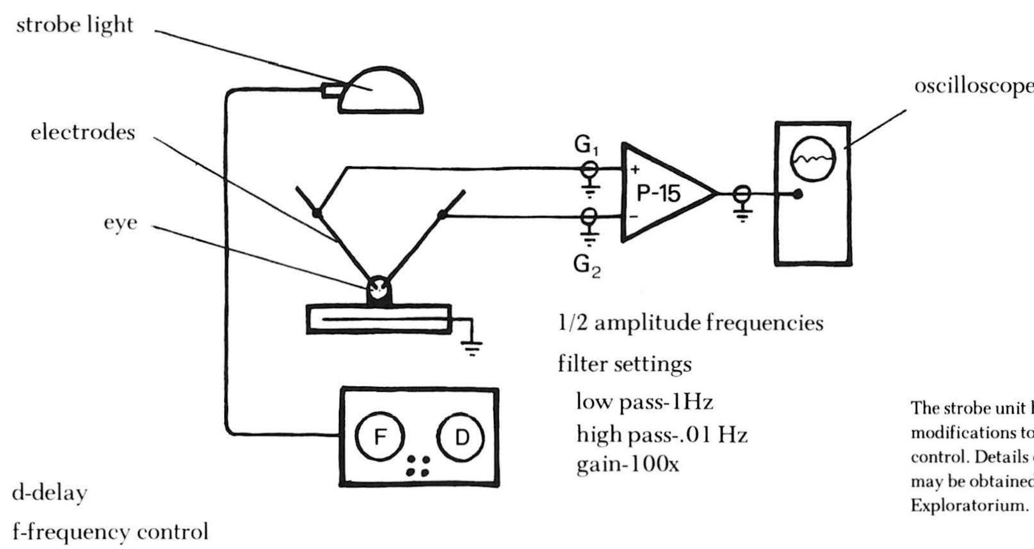
Ringer's. This replenishes the electrolytes that the eye needs to stay alive. Crayfish Ringer's consists of:

5 gal. Distilled water
228 gm. Sodium chloride
37.6 gm. Calcium chloride
10 gm. Magnesium chloride
7.6 gm. Potassium chloride
3.7 gm. Sodium bicarbonate

Both eyes are removed at the same time and one is put into the refrigerator immersed in Ringer's for later use (keeps up to 4 days).

The electrodes are made by crimping #000 stainless steel insect pins into stainless steel capillary tubing. These electrodes are then inserted into ball and socket joints (available from Grass Instruments) and connected to the preamp (P-15 Grass Instr.). One electrode is inserted into the retina and the other superficially into the eye. The signal level is very low (5 microvolts) so the eye/electrode is kept in a Faraday cage. The preamp filters are set to pass only signals in the frequency range of 1 to 10 Hz. The amplified signal is then fed to the oscilloscope.

The photostimulator used is a Grass Instr. PS-2D which provides all of the necessary controls. The knobs of the photostimulator are attached through a



The strobe unit has special modifications to allow visitor/user control. Details of these modifications may be obtained by contacting the Exploratorium.

Velcro (R) linkage to the outside of the exhibit to prevent damage to the stimulator from over-zealous usage. The white tungsten source and strobe are made to appear to come from the same place with a pivotable mirror.

Critique and Speculation

Because of the nature of the exhibit, it must be placed in a dark area. The eye has a short lifetime (5 to 8 hours) once it is separated from the crayfish and the response of the eye to stimuli diminishes during the day. Keeping the eye cool makes it last longer.

In our exhibit the frequency knob is spring-loaded to return to low frequency when it is released. This can be as frustrating as restroom sink faucets which do the same thing and was included only as an effort to keep the eye from being over stimulated and "worn out" before the day is over.

Additions and Changes (1990)

Since we wrote this recipe, we have modified the exhibit so that the eye is exposed only to strobe light, rather than continuous white light or strobe. Visitors can choose to expose the eye to equally spaced single flashes of light or to pairs of flashes. Visitors can still select the time between flashes. To make the light flash, the visitor must hold down the button. This means that the eye is exposed to light only while the visitor is at the exhibit.

The eye will stop responding if it is exposed to too much light. When you are setting up the exhibit, we suggest turning off the overhead lights before you remove the eye from the refrigerator. The exhibit must be placed in a dark area. Even with these precautions, the eye has a short lifetime (5 to 8 hours) once it is separated from the crayfish. The response of the eye to stimuli will diminish over the course of the day. Keeping the eye cool will make it last longer. In general, fresh eyes work better than ones that have been stored for some time.

Related Exploratorium Exhibits

INFORMATION PROCESSING AND ENCODING
- Language of Nerve Cells
- Muscle Stretch
- Watchful Grasshopper

To do and notice:

Turn on the white light bulb and notice the crayfish eye under the black plastic cover.

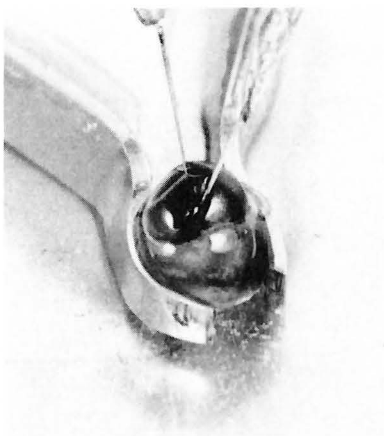
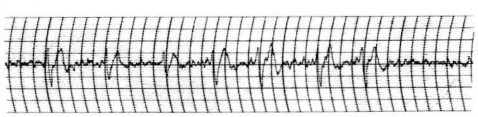


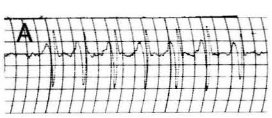
Photo Susan Schwartzenberg

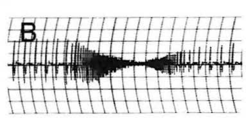
Two electrodes are penetrating the eye. The electrodes measure electrical changes which occur in the eye when it responds to light. The oscilloscope displays these electrical changes visually.

Cast a shadow over the crayfish eye. Notice that as the amount of light falling on the eye changes, the oscilloscope trace also changes.



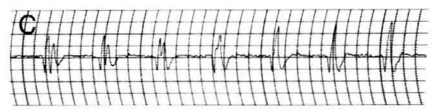
Release the white light and press the strobe light button. Notice that under the flashing light the eye is responding to the rapid changes in the light level. This is similar to a quickly passing shadow. A



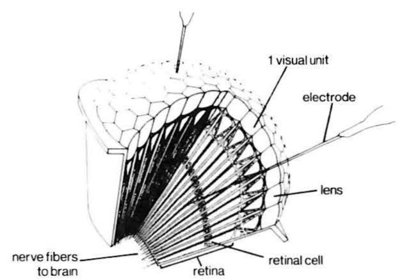


Increase the number of flashes by adjusting the flashes-per-second knob. Notice that as the number of flashes increases the size of the pulse on the oscilloscope decreases. The eye is adapting to a new light level. B

Slowly adjust the double-flash knob. (Be sure the black button below the knob is held down while you adjust it.) You can see how the eye responds to the double flash by the recording of the double pulse on the oscilloscope. At a certain point the light is flashing so quickly that the eye sees it only as one flash, thus one larger pulse is recorded on the trace. The eye is unable to distinguish the two flashes at this speed. This is how motion pictures work for us. It is a phenomenon known as flicker fusion. C



What is going on:



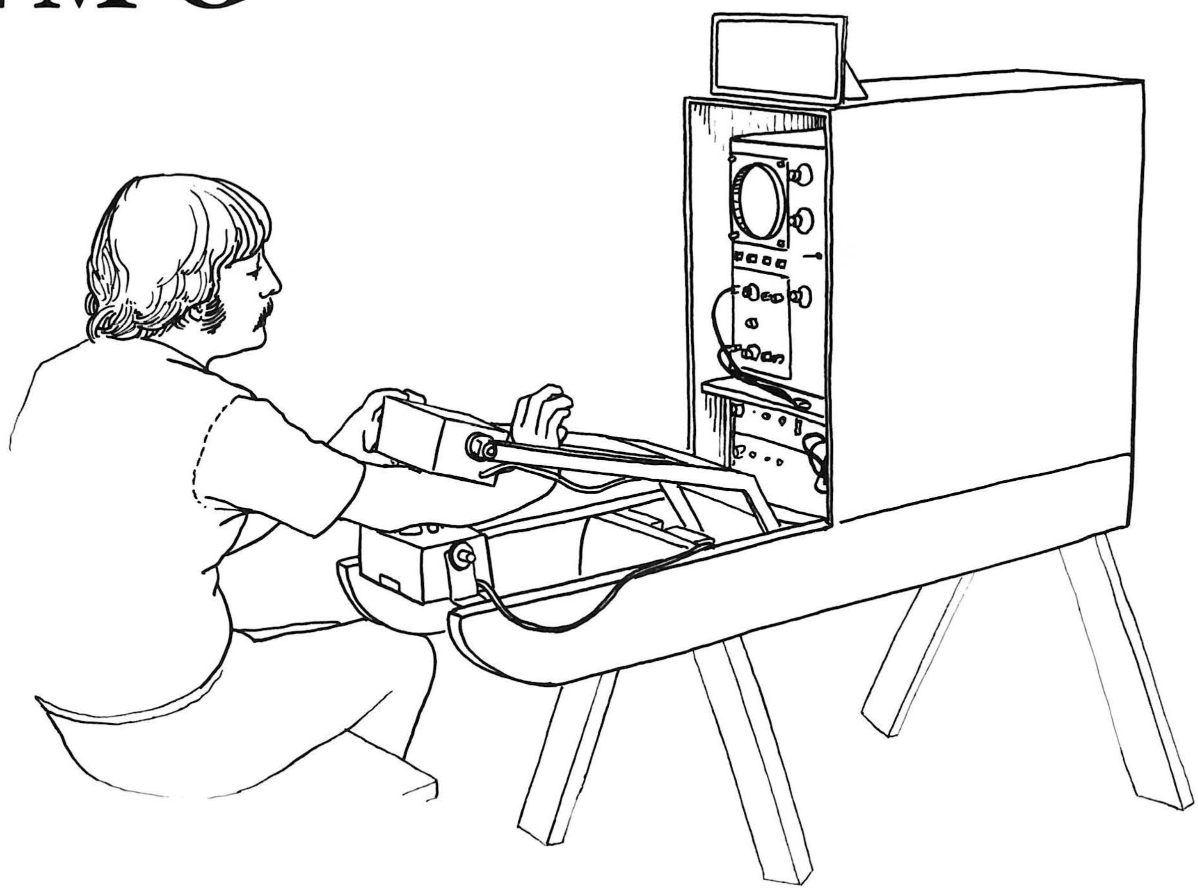
Crayfish and grasshoppers seem to be most sensitive to moving dark objects and changes in light intensity. Their eyes do not see fine detail.

The compound eye is composed of many small visual units, each of which has its own lens which focuses light on a small group of retinal cells. Each small "eye" sees only a fraction of the visual field. The combined information from each "eye" plus other of the animal's senses provides a view of the surrounding world.

In this preparation the electrodes are penetrating cells within the retina. These cells are light sensitive. When light falls upon them chemical changes occur which cause electrical voltages. It is these small electrical voltages you see displayed on the oscilloscope.

If the eye were connected to the crayfish these electrical signals would be "added" and "subtracted" by other cells to form nerve impulse signals which would be sent to the animal's brain.

EMG



Description

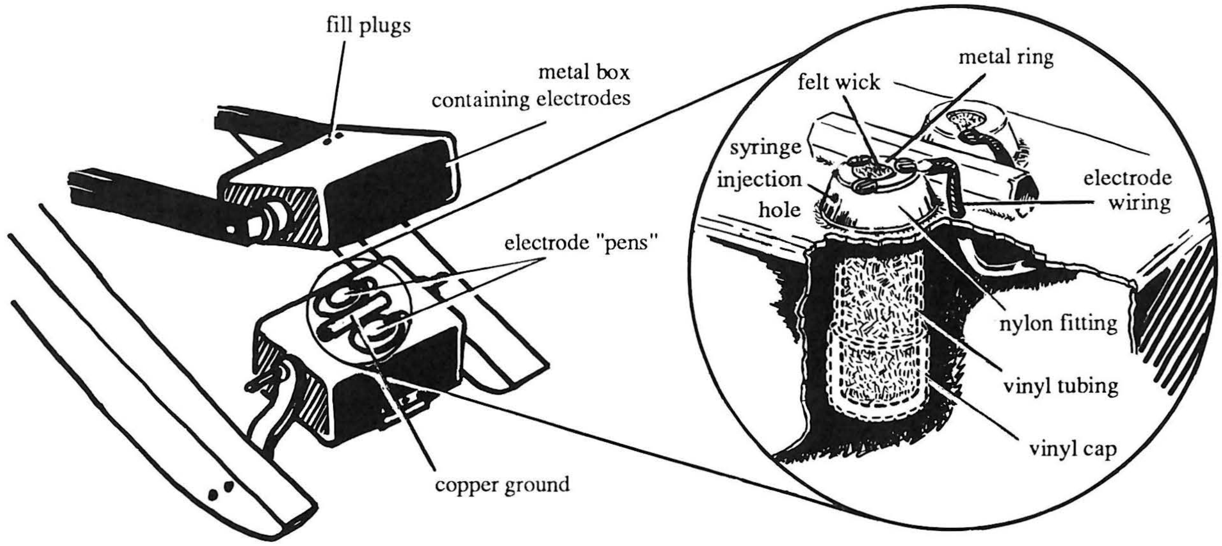
The EMG (ElectroMyoGram) demonstrates that electrical activity is associated with muscular contraction. The visitor places a bared forearm between two pairs of recording electrodes; then, while making a fist or moving their hand or fingers, they (and others) can listen to the audio signals coming from the oscilloscope as well as see the display of the waveforms on the screen. Two sets of muscles can be monitored, one which bends the hand down and the other up.

Construction

The EMG is a wooden box containing the oscilloscope and amplifier electronics fastened to a stand that is built like a sawhorse but with two horizontal rails that support the equipment. The front of the box is covered with clear acrylic. The visitor sits in a chair in front of the exhibit.

The oscilloscope enclosure contains a Tectronix 533 oscilloscope with dual channel plug-in, two P-15 Grass Inst. amplifiers, and an audio amplifier and speaker. The vertical signal out from the scope provides the audio. Shielding the amplifiers on three sides proved adequate.

The electrodes, which are in the two metal boxes at the front end of the stand, had to be nondisposable and easy to apply. They might be imagined as



modified felt tip pens. These bullet-shaped "pens" were machined with a reservoir which holds dilute EKG gel. A felt wick runs from the reservoir to the top of the electrode. The reservoir is connected to the outside of the box via vinyl tubing and nylon fittings which provide the necessary insulation from the grounded box. This box serves as a shielding device as well as a mounting for the electrodes.

Critique and Speculation

The electrode arrangment used on EMG was designed for unsupervised use and was therefore made easy to apply and long lasting. The only drawback to this design is that it is often very uncomfortable to use. In a moderately supervised situation, the electrodes could be held in a strap that would wrap around the visitor's arm; this would be simpler and more comfortable.

Additions and Changes (1990)

Instead of using EKG gel in the reservoir, we now use a mixture of two parts saline solution and one part alcohol. We fill the reservoir by using a syringe to inject the solution through a small hole in the nylon fitting. Depending on temperature and number of visitors, you may have to refill the reservoir once or twice a day.

When you wire the electrodes, we suggest you leave extra slack in the wire. The ends of the electrode wires tend to corrode at the electrode. When this happens, we cut off the end of the wire. Because we have slack in the wire, we can do this without replacing the entire wire.

We also suggest that you weld the copper ground in place, rather than bolting it. If you bolt the copper ground in place, saline solution can seep under the copper strip, forming a "salt bridge" between the electrodes and causing a short circuit.

Lastly, to prevent visitors from smashing their arms between the recording electrodes and the upper box, we have welded a steel bar in a position that keeps a 2-1/2" gap between the lower box and the upper box.

Related Exploratorium Exhibits

DETECTION AND MEASURING DEVICES

Sweat Detector
Heart Beat

NEUROMUSCULAR ACTIVITY

Grasshopper Leg Twitch
Heart Beat
Language of Nerve Cells
Muscle Stretch

Exploratorium Exhibit Graphics

The exhibit graphics is a 4 page booklet.

The first 2 pages are a step by step procedure of how to place your arm between the electrodes for a good recording. The procedure is illustrated with several photographs.

What is going on:

E. M. G. is the abbreviation for a mechanism which records the electrical activity of muscles. Every time your muscles contract electrical activity occurs which can be detected and recorded.

There are two sets of electrodes in contact with your skin. The set of electrodes in the top block pick up the electrical activity of the upper group of muscles in your forearm. This activity is recorded as vertical spikes on the top trace of the scope.

The bottom set of electrodes record the electrical activity in the lower group of muscles in your forearm. This activity is recorded as vertical spikes on the lower trace of the scope.

When you clench your fist both traces of the scope are active because both groups of muscles in your forearm are being used.

You can experiment by twisting your hand into different positions or moving separate fingers. Watch the oscilloscope to see which muscles you are using.

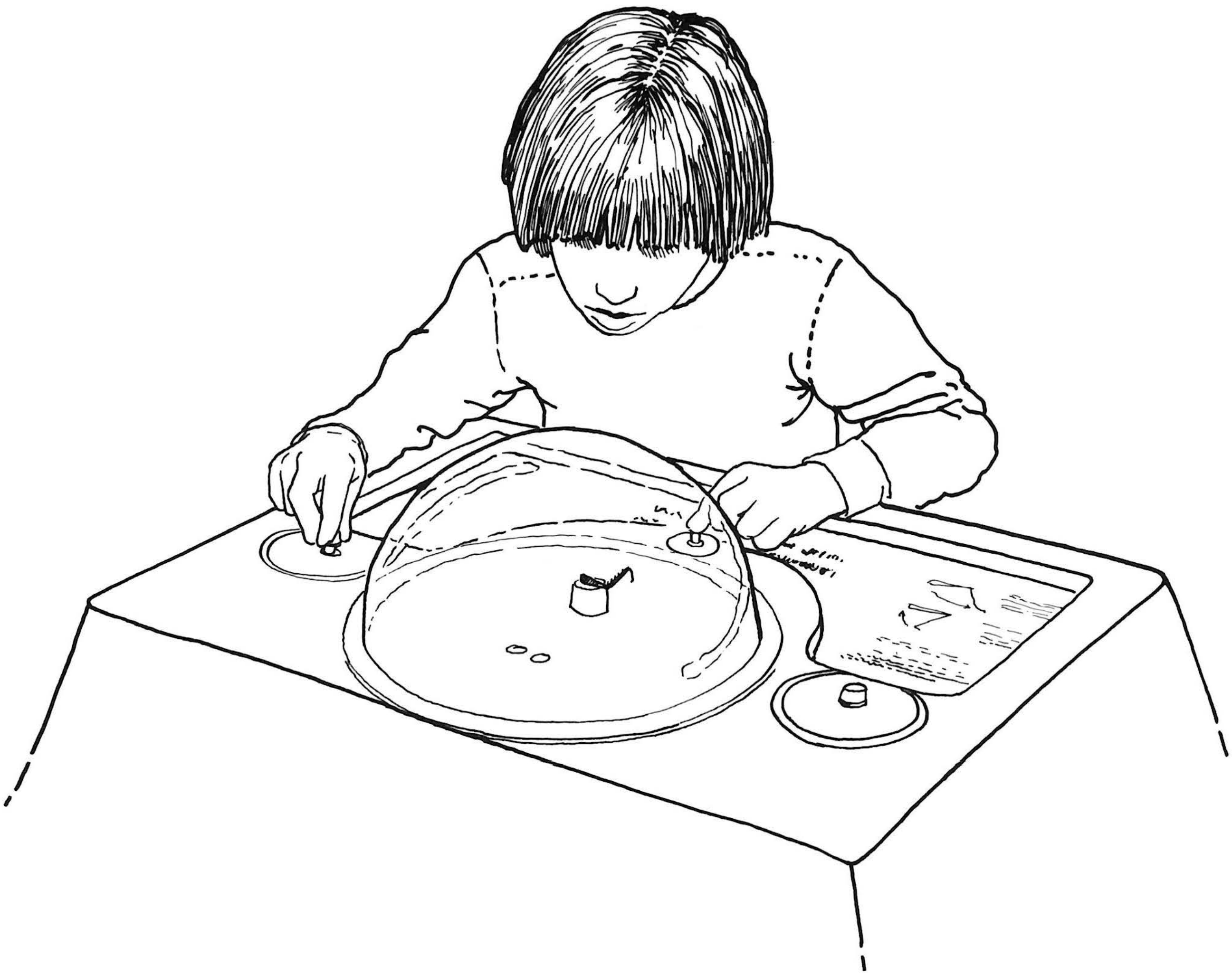
To see and hear a recording of the electrical activity in your heart, see the Heart Beat exhibit.

Some other things to notice:

If the electrodes do not make firm contact with your skin this exhibit will not work properly.

If this has happened you will see a wavy line on one or both of the traces. The wavy line occurs because the electrodes are picking up other electrical signals around you, and your body is acting like an antennae. (This is called 60 cycle hum.)

Grasshopper Leg Twitch

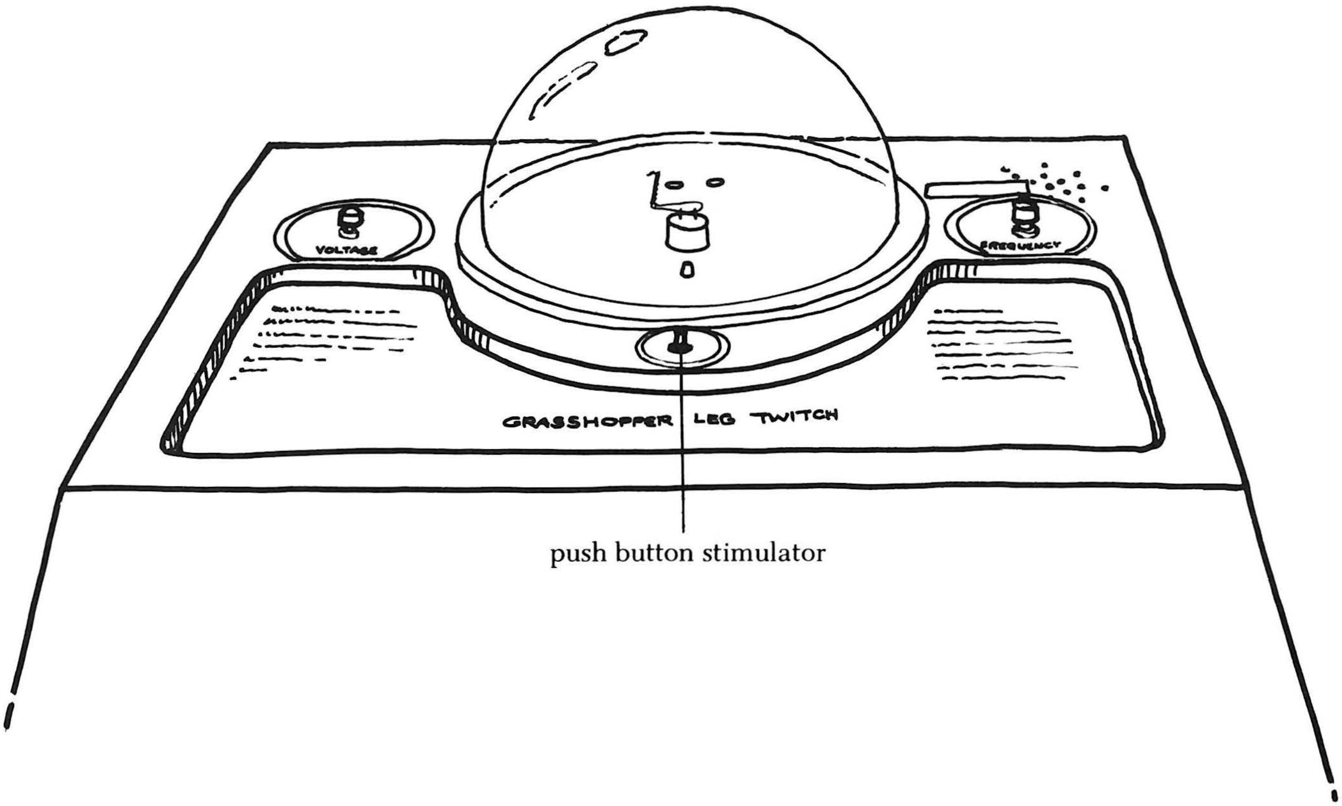


Description

This exhibit demonstrates the effect of small electrical shocks on the leg muscles of a grasshopper. The visitor can adjust how many pulses to send to the leg and the voltage of the pulses. By experimenting with these two variables, the visitor is able to determine some of the physiological aspects of muscle and establish a connection between electrical activity and muscle contraction.

Construction

Our exhibit is pyramidal in shape, about 36" tall. The leg is mounted on top of a plastic block which acts as a light guide and electrode carrier. The block and leg are covered with an 10" diameter plastic hemisphere to protect the leg. Rear-lit graphics as well as the user controls surround the dome. The stimulating electronics were built with NE555 timer IC's using the application notes for those chips. We used two



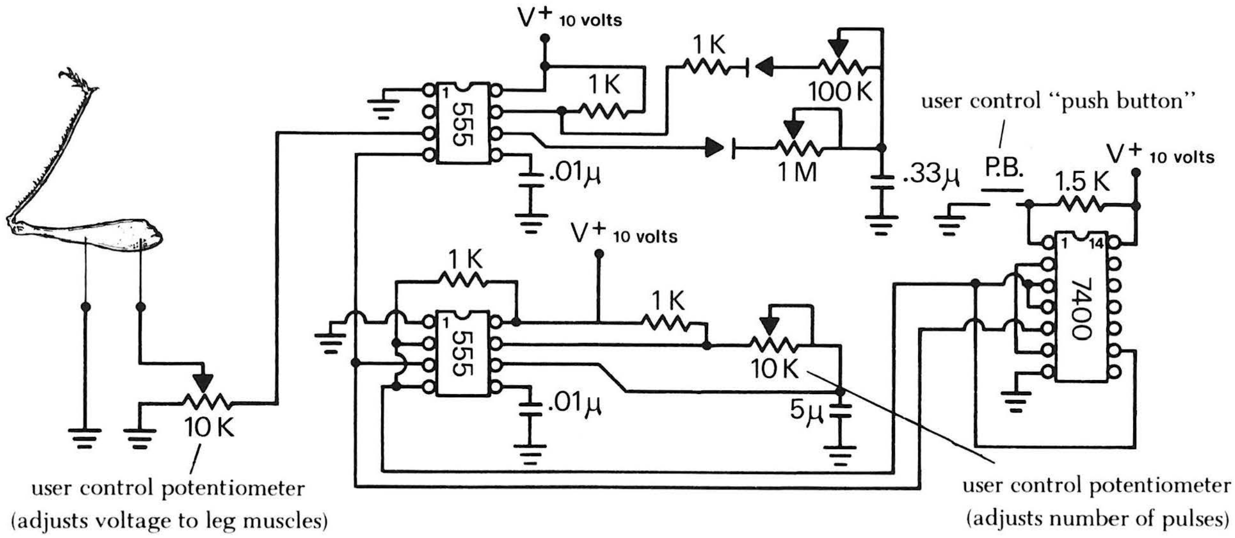
push button stimulator

555's, one wired as a monostable multivibrator to control the number of pulses (1 to 4) issued from the other 555 which is wired as an astable multivibrator (frequency approx. 10 Hz.). The output voltage can be varied by the user from 0 to 10 volts by a potentiometer in series with the output of the 555's. The voltage is limited by a series potentiometer. The output is also coupled to a simple one-transistor amplifier to make the pulses audible. If you have a pulse generator handy it may be substituted for our little circuit (A 9 Volt battery and button will work also!).

The animal used in our exhibit is the **Desert Locust, Schistocerca nitens.** When inserting the electrodes, it is important not to penetrate the leg muscles too deeply, and, with experimentation, it is possible to stimulate specific sets of muscles. Other insect legs will work but you will have to experiment.

Critique and Speculation

The pyramidal shape of this exhibit has proven impractical. People sometimes trip over the corners which protrude out from the center of attention of the exhibit, and the shape makes for difficult wheelchair access. A voltage level indicator might be of use since visitors would then be able to see the exact threshold level. The insect used in this exhibit is kept and raised at the museum so there will always be a ready supply. Unfortunately, this insect is an agricultural pest in California and we must have a permit to keep and raise them. Check with your local agricultural department for details on the animal you choose to use.



Additions and Changes (1990)

We now use *Schistocerca americana americana* instead of *Schistocerca nitens.*

The original recipe includes no information on how to separate the leg from the grasshopper. A grasshopper will drop its leg if you hold onto the leg. This is a natural adaptation. If done correctly, it does not cause the grasshopper to suffer.

It's best to hold the leg so that it is 80% straight (a 150-degree angle) before the insect drops it. A leg that starts out straight will display a more dramatic twitch.

We suggest you wear gloves when working with grasshoppers to avoid being scratched by the grasshopper's barbs.

Related Exploratorium Exhibits

NEUROMUSCULAR ACTIVITY

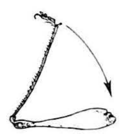
E M G
Heart Beat
Language of Nerve Cells

Set the red voltage knob to the red dot.

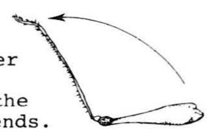
Now press the black stimulator button and watch the grasshopper leg twitch.

Adjust the voltage to different levels.

At low voltage levels the leg contracts.



At higher voltage levels the leg extends.



Set the yellow frequency knob to 2

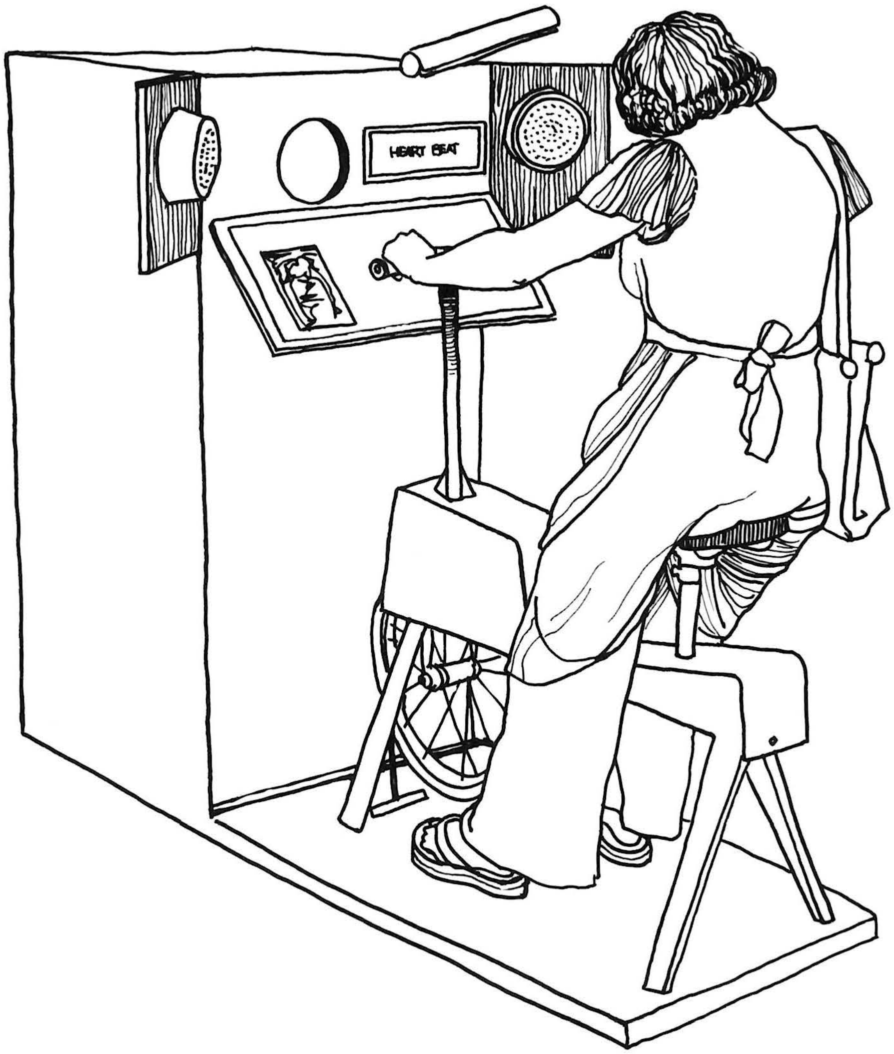
Press the black stimulator button.

Notice that the leg has twitched twice, and two clicks are heard.

The frequency knob adjusts the number of voltage pulses which are given to the leg. Each pulse is heard as a click when the black stimulator button is pressed.

Experiment by adjusting both knobs. Watch the leg to see the effect that the different combinations will make.

Heart Beat

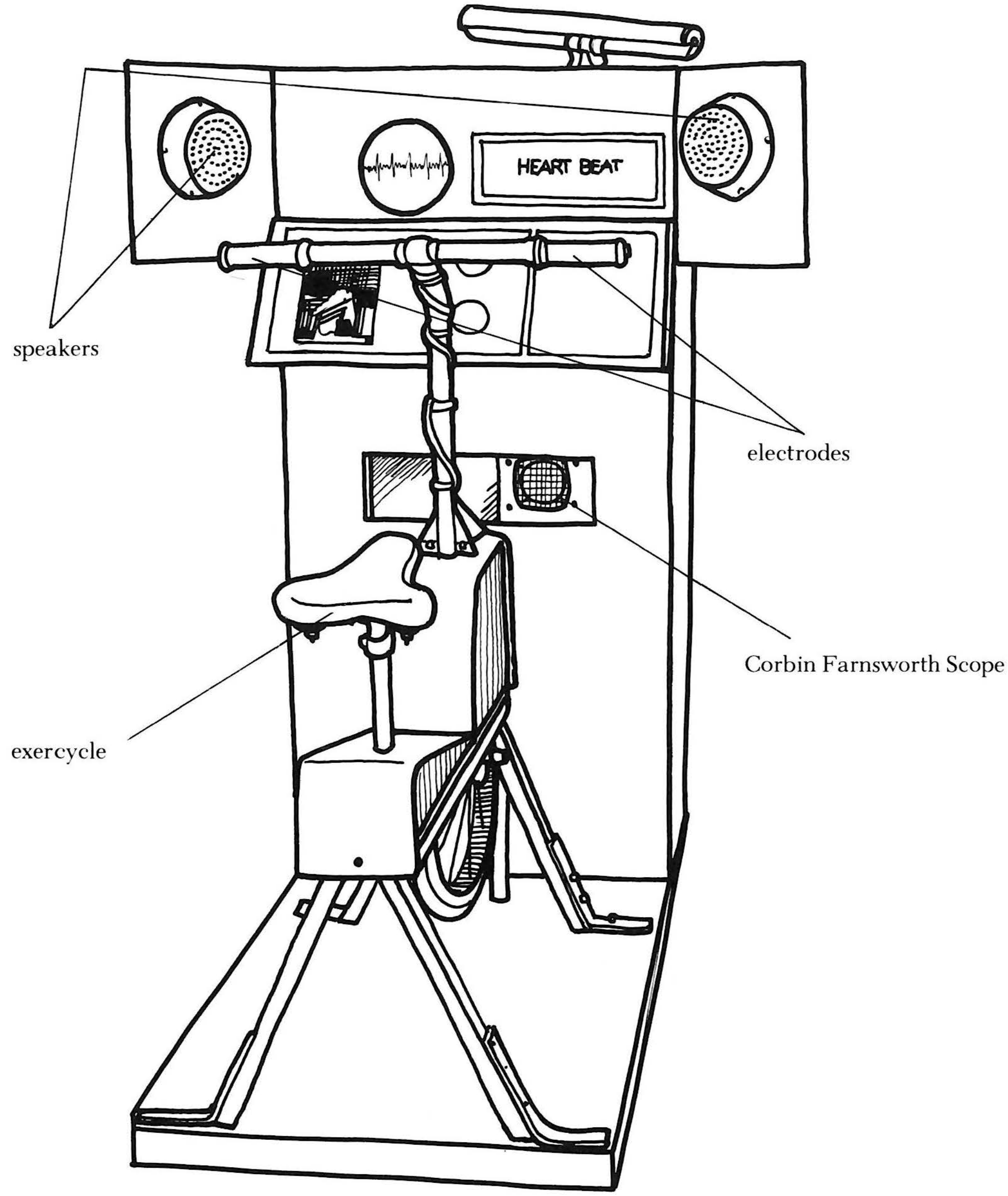


Description

The visitor sits on an excercise cycle and holds the handlebars which act as electrodes. The electrical signals to the heart muscles are picked up and amplified, then displayed on an oscilloscope and played through a speaker. The user then "rides" the cycle for a brief period of time and observes the change in heart rate after the small amount of work.

Construction

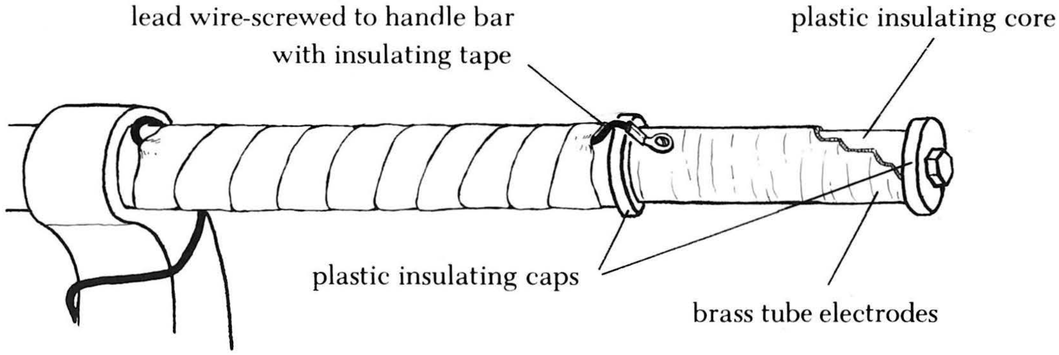
The excercise cycle is firmly mounted to a base plate in front of a large box containing the oscilloscope, biological and audio amplifiers, and speakers. The handles on the cycle act as the electrodes and are electrically insulated from the cycle frame. We initially gold plated these brass tube electrodes for better electrical contact with the user, but the gold quickly wore

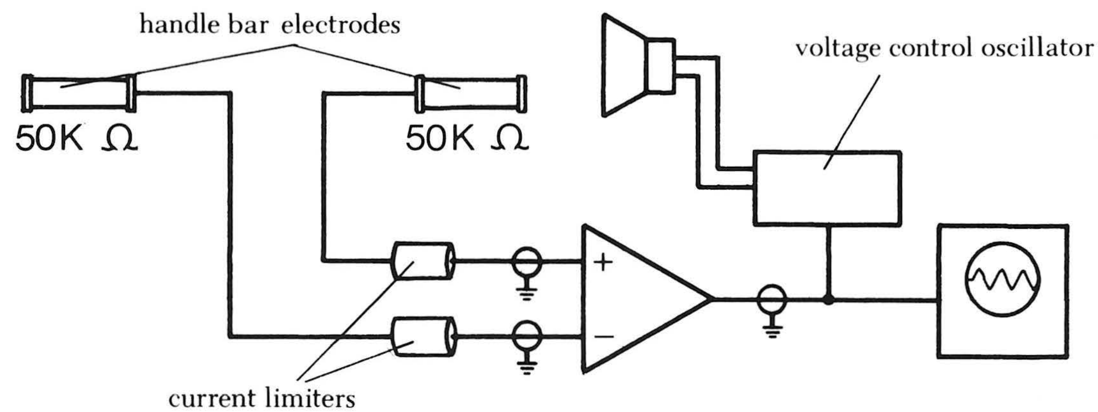


off and was found to be unnecessary. The small electrical signal is then amplified using a Corbin-Farnsworth Inc. Scopette Model SCD-2 cardioscope before being sent out to the larger oscilloscope display and audio circuits. The cardioscope we used is no longer available but can be easily replaced with any biological amplifier (such as the Grass Instruments P-15 which works very well).

When no one has their hands on the electrodes the apparatus picks up 60 Hz. hum from the environment and can make a lot of noise. To solve this problem, a phase-locked-loop circuit tuned to 60 Hz. was built to turn the audio amplifier's output off when nobody is using the exhibit. The audio signal is produced by a voltage controlled oscillator (VCO) which puts out a trianglular wave form that is pleasant to listen to. The frequency of this oscillator is dependent on the voltage present at the output of the cardioscope (higher voltage, higher frequency).

handle bar cutaway detail





Critique and Speculation

The excercise cycle has been a continuous maintenance problem. The public applies excessive force to the cycle and has managed to break pedals off, break seats off, and even bend the frame of the cycle! (We no longer use the pedals. People pedal in the air to raise their heart beats.) A sturdy welded steel cycle may suffice but has not been tested by us (The Oregon Museum of Science and Industry (OMSI) has designed a heavy duty version and is using it successfully). The cycle might even be eliminated in future versions since any type of excercise such as running in place, push-ups, and jumping jacks will have the same effect. The elimination of the cycle would also make the exhibit accessible to people in wheelchairs.

Additions and Changes (1990)

Since this recipe was written, we have replaced the cardioscope with a Grass Instruments P511 pre-amplifier and power supply to amplify the electrical signal. We use the following settings:

Calibrator: 10 mv
1/2 Amp Low Frequency: 3 Hz

Amplification: 20 x 100
1/2 Amp High Frequency: 0.1 kHz
60 Hz filter: IN

To prevent visitors from pulling on loose wires, we have taped down all wiring with electrical tape. We also replaced the bicycle seat with a wooden seat made in the Exploratorium machine shop. The wooden seat has lasted for years.

Exploratorium Exhibit Graphics

TO DO AND NOTICE

Sit quietly on the exercycle and put both hands on the gold plated handle bar electrodes.

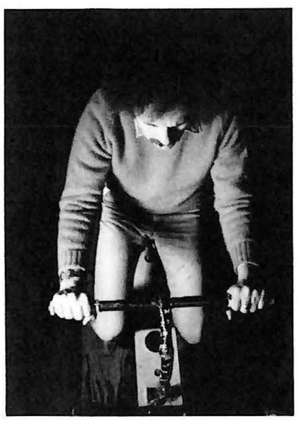
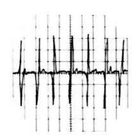


Photo Nancy Rodger

Now watch the oscilloscope and notice the vertical spikes.

Pedal vigorously for about 15 seconds, then hold still and watch the scope. (keep holding the handle bars.)



Notice that the oscilloscope is recording a greater number of vertical spikes.

WHAT IS GOING ON

Every time your heart beats, electrical activity is released throughout your body. The gold plated handle bar electrodes pick up the electrical activity from your hands and record each beat as a vertical spike.

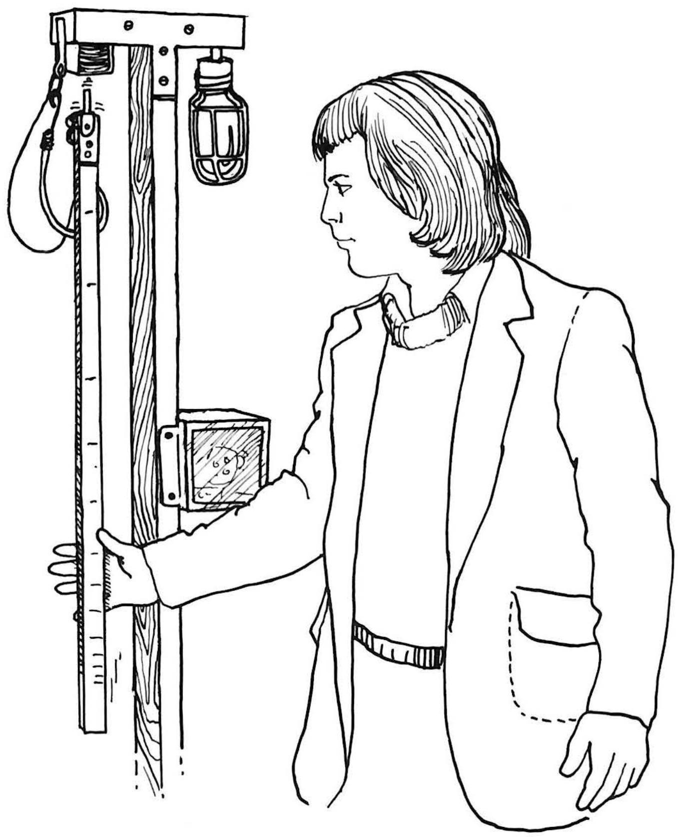
You are also hearing an electronic representation of each heart beat.

When you pedal your heart beats faster because you have exerted yourself. The faster your heart beats, more vertical spikes are recorded and more "beats" are heard.

Related Exploratorium Exhibits

E M G
Grasshopper Leg Twitch

Reaction Time



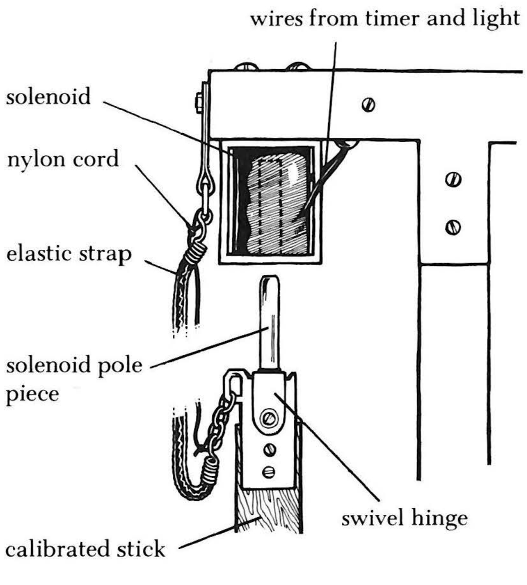
Description

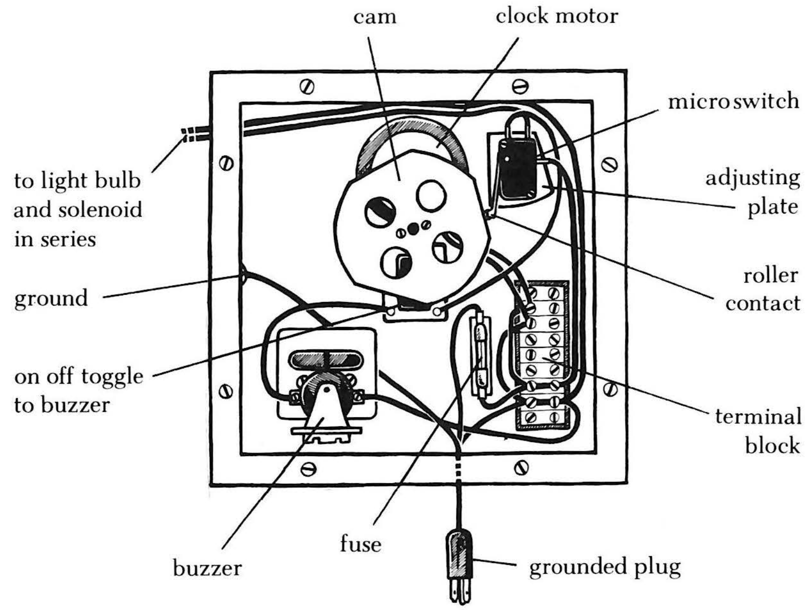
This exhibit allows a person to test his/her reaction time to a variety of stimuli with a very simple device. A stick labeled with time intervals falls at a random time through the fingers of the subject. At the time the stick is released, a light goes out (visual stimulus) and a relay clicks (audio stimulus). The person then tries to grab the falling stick as quickly as possible. The number under the fingers of the person is the reaction time.

Construction

The entire exhibit is built on a tall stand made of 1 1/2" square steel tubing with a heavy base. The lamp (which provides the visual stimulus) and the solenoid which holds the stick up are mounted on the opposite sides of a "T" on top of the stand. The pole piece of the solenoid is mounted on the top of the stick on a loose hinge to reduce the chance of breakage. The lamp is wired in series with the 120VAC solenoid so that the current (and hence the strength) of the solenoid can be controlled by changing the wattage of the lamp. We use a 25 watt rough service lamp. The rough service lamp is necessary because of the many shocks it must endure.

A microswitch riding on a motorized cam (2 RPM) determines when the stick is dropped. The cam has 3 irregularly spaced flat spots on it which cause the microswitch to turn the lamp and solenoid off unpredictably while clicking a large relay on. The entire timing





assembly is enclosed in a clear plastic box which is screwed to the upright of the exhibit. The stick is connected to the "T" near the solenoid with an elastic strap (to cushion the fall if the person misses completely) and a piece of nylon cord (to keep the elastic from being stretched too much). The timing marks on the stick start at 0 (where the person's fingers go at the start) and increase in .02 second intervals to .34 seconds. Below is a table with the times and respective distances in inches and centimeters:

Time (sec)	In.	Cm.
.02	.076	.19
.04	.307	.78
.06	.691	1.75
.08	1.23	3.12
.10	1.92	4.88
.12	2.76	7.02
.14	3.76	9.56
.16	4.92	12.48
.18	6.22	15.80
.20	7.68	19.51
.22	9.29	23.60
.24	11.06	28.09
.26	12.98	32.97
.28	15.05	38.23
.30	17.28	43.89
.32	19.66	49.94
.34	22.19	56.37

$$d = \tfrac{1}{2}gt^2 = \tfrac{1}{2}(980t^2)\text{cm}$$

g = acceleration of gravity
t = time in seconds

Related Exploratorium Exhibits

Balancing Stick

Exploratorium Exhibit Graphics

To do and notice:

1. Insert stick in coil
2. Hold fingers apart at 0 point
3. Wait for the stick to fall, and then try to catch the stick by closing your fingers. The number beneath your fingers when you catch the stick shows the time it took you to react in hundredths of a second. The light goes on and off, and the relay clicks at the instant the stick starts to fall.

Does it matter how far apart your fingers are at the start?

Does it matter whether you look at the light or the falling stick?

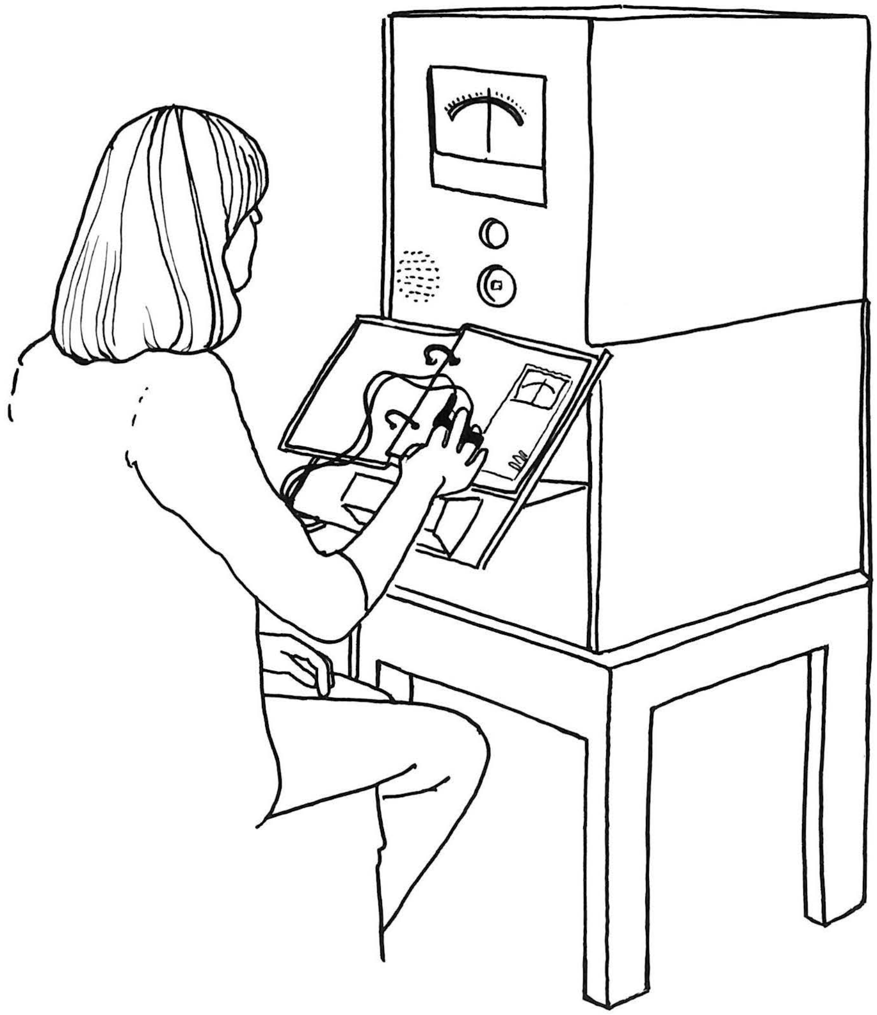
You can shut your eyes and react only to the click. Is your reaction time the same?

Notice that the numbers on the stick get farther apart because the stick accelerates and falls more and more rapidly the farther it falls. Therefore the stick falls a longer distance in each 1/100th of a second.

What is going on:

When you notice the light going off or the stick falling, the signal in your eye must go to the brain, be sent to the proper part of your brain which controls your muscles, and then send the signal to your muscles. Although it takes some time for the signal to travel along each nerve, the major delay in your reaction occurs at the junctions between the different nerves involved and between the nerves and the muscles of your fingers. Even with practice very few people can react in less than 16/100ths of a second.

Sweat Detector



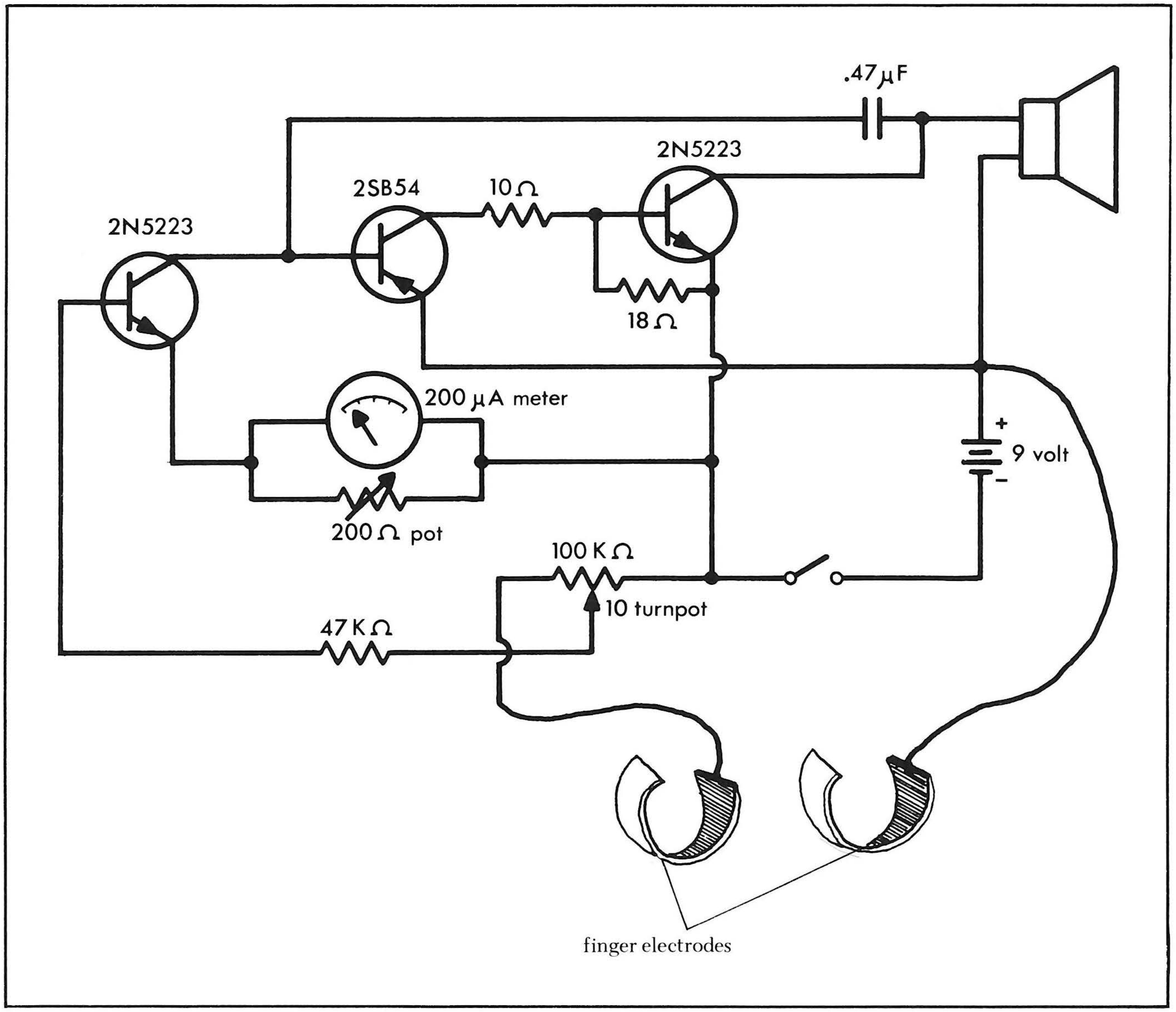
Description

The visitor straps electrodes on two fingers of one hand. An adjustment is made for the person's electrical resistance. They are then presented with a variety of stimuli to which they can observe their galvanic skin response (GSR). The response is in the form of a small change in the resistance of the skin due to the small amounts of perspiration caused by the stimuli. The response is observed on a meter and heard as a changing tone from a speaker.

Construction

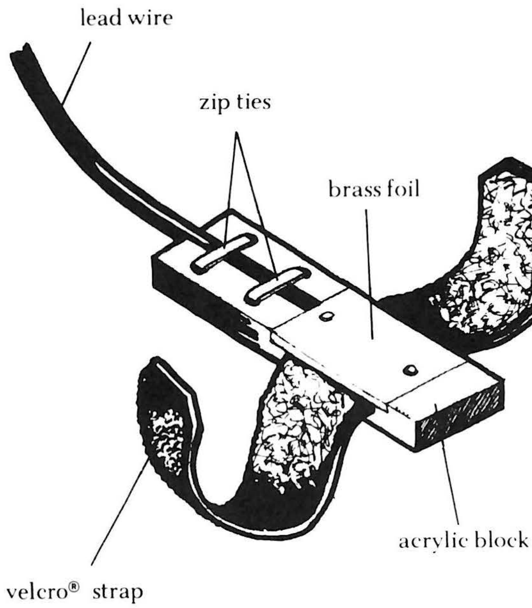
Our exhibit is constructed around a Radio Shack "lie detector" circuit which we slightly modified to our own needs (see schematic). Our addition is the 200 microamp meter and shunting potentiometer (200 ohm) so the user will have visual indication as well as audio (valuable for people who are deaf). The single turn pot R5 has been replaced with a much more accurate 10 turn pot mounted on the front of the exhibit. This pot is used to adjust for the vis-

Sweat Detector schematic



itor's individual "normal" resistance which varies widely from person to person. There is a visual and an audio stimulus, either of which can be triggered by the subject's free hand or by a friend. The audio stimulus consists of a large heavy solenoid which, when activated, makes a very loud sudden noise. We have found it necessary to restrict the frequency of the solenoid firing to once every six seconds to increase the life of the solenoid and make the noise more random and surprising. The visual stimulus is provided by a small inexpensive camera strobe which flashes, when its button is pressed, through a hole in the exhibit under the meter. The subject must be seated and in a relaxed position for best results so we provide a chair. The electrodes are made of scraps of acrylic plastic wrapped with brass foil (shim stock). Velcro straps keep the electrodes on the person's fingers and heavy test lead wires connect the electrodes to the electronics.

electrode detail



Critique and Speculation

The only thing which might be added to the exhibit would be an indicator lamp to tell the person that the adjusting pot is way out of range (which causes a chirping sound to issue from the exhibit) and to readjust to the center position. A pleasant surprise to us was that the finger electrodes last an amazingly long time even though they are relatively delicate.

Additions and Changes (1990)

Since this recipe was written, we have rebuilt our Sweat Detector exhibit. The new exhibit is built around a circuit constructed in our shop. Unlike the "lie detector" circuit, the new circuit automatically adjusts to zero with each visitor. We also built a new noise maker, strobe unit, and electrode.

Related Exploratorium Exhibits

DETECTION AND MEASURING DEVICES

- **E M G**
- **Heart Beat**

HABITUATION

- **Featherworm**
- **Watchful Grasshopper**

PROTECTIVE BEHAVIOR AND STRUCTURE

- **Hot-Cold**

Exploratorium Exhibit Graphics

The exhibit graphics consist of an 8 page instruction booklet with photographs demonstrating how to use the exhibit.

1. SWEAT DETECTOR a device which measures the electrical conductivity of your skin.

2. Photo - placement of fingers in the electrodes.

Place your finger on the metal electrode plate and wrap the flaps around your finger.

Use two fingers.

Relax your hand.

3. Photo - correct needle position on meter.

Turn the knob in the center of the panel until the needle is stabilized at 4.

4. Photo - hand reaching into opening.

Reach into the opening to your lower right with your free hand. You will find two buttons, press one.
Notice that the needle has jumped and the sound has changed.

5. Photo of meter.

Reset the needle to 4 and press the same button again.

Notice that the needle moves less than the time before.

Repeat this a few more times until the needle no longer moves.

Now try the other button.

6. and 7. WHAT IS GOING ON;

The two electrodes on your fingers measure the electrical conductivity over your skin.

If you are startled by the loud sound, or by the flashing light, your autonomic (part of your unconcious) nervous system, causes you to perspire slightly more than usual. This slight increase in wetness causes the surface of your skin to be a better conductor. The electrodes detect this change and the needle jumps.

When the stimulus is repeated over and over, you become used to it and no longer react, this is called habituation. As a result the needle remains at 4.

Your autonomic nervous system controls the body functions you do not think about, such as heart beat rate, muscle tone, digestion, breathing, etc. Although you probably jumped when you heard the loud sound or when the light flashed, the "sweat reaction" is your unconcious response.

8. SOME OTHER THINGS WHICH MIGHT EFFECT THE NEEDLE.

Think of something that makes you angry, or scares you, or that is exciting.

Breath rapidly or hold your breath for a short time.

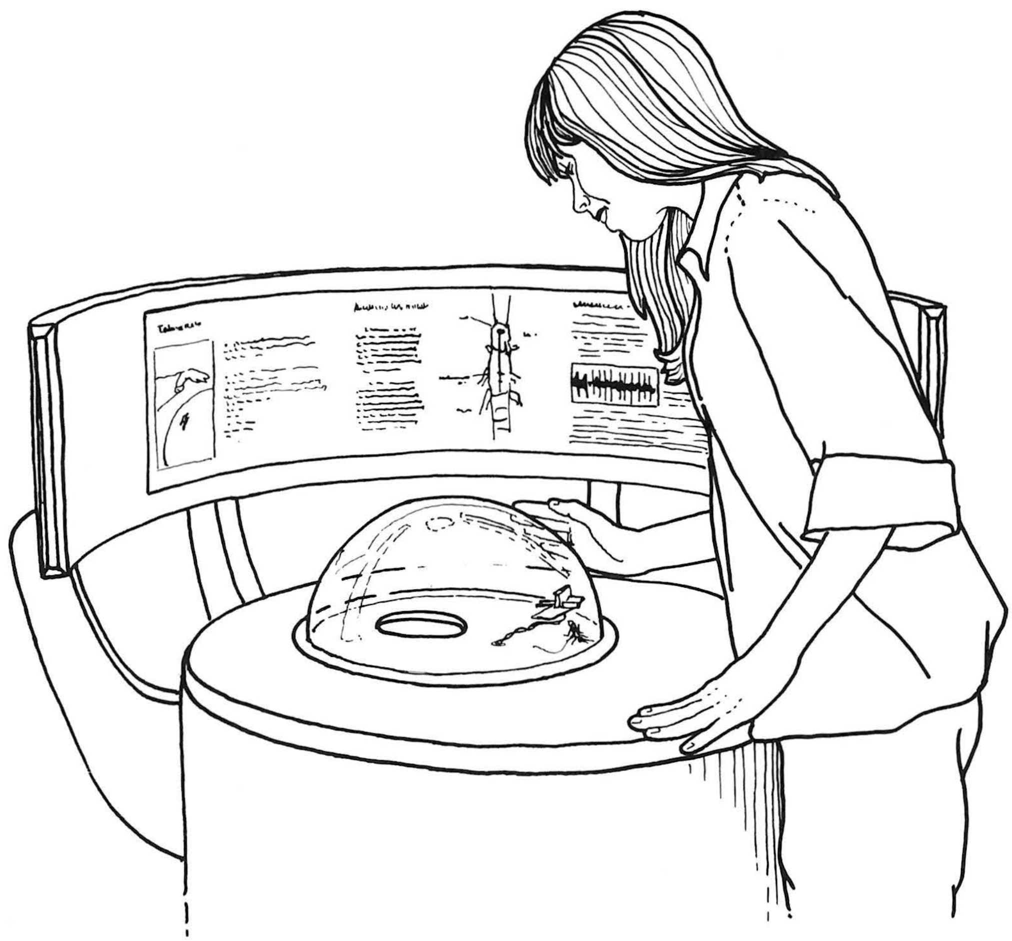
Pinch yourself.

Have someone kiss you, or tickle you.

Experiment trying different things.

Recipe No. 124

Watchful Grasshopper



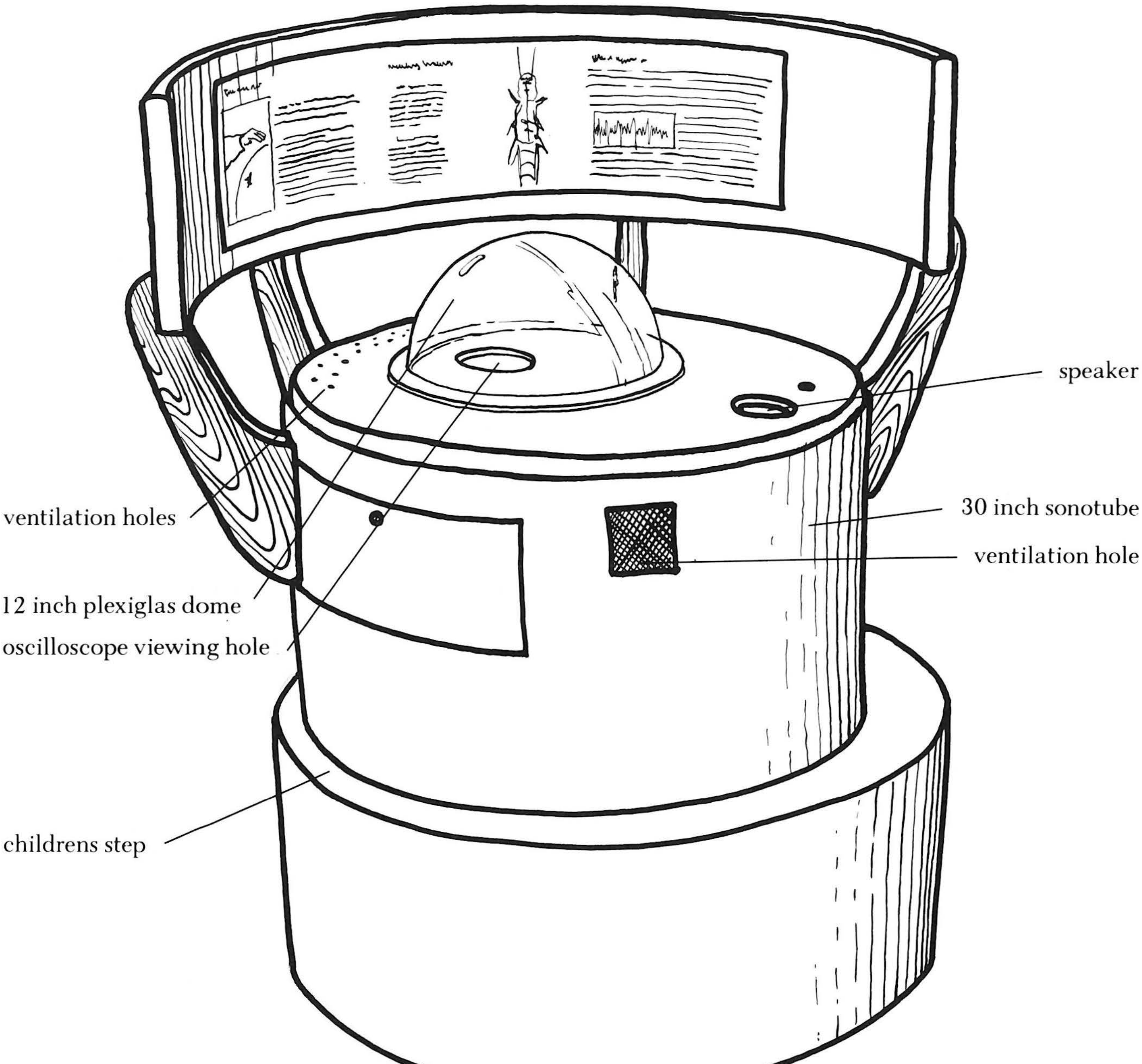
Description

A grasshopper **(Schistocerca Nitens)** has electrodes implanted on either side of its ventral nerve cord to pick up signals traveling along it. Those impulses associated with the detection of movement by the grasshoppers eyes are especially large and easily detected. Long thin wires enable the grasshopper to freely roam about its area while the visitor stimulates visual responses by making sudden motions near the grasshopper. Habituation of the nervous system can be observed by repeated movements. The electrical activity is displayed on an oscilloscope as well as being amplified and played through a speaker.

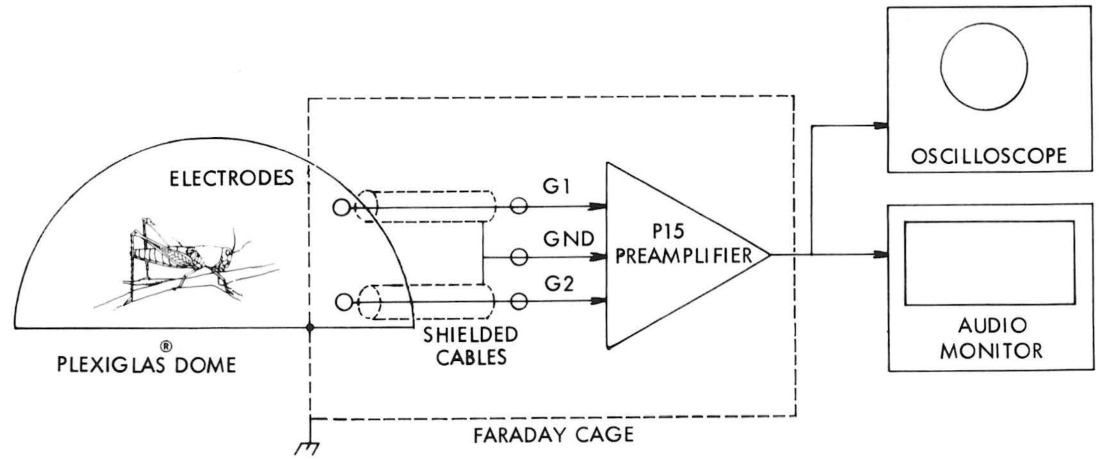
Construction

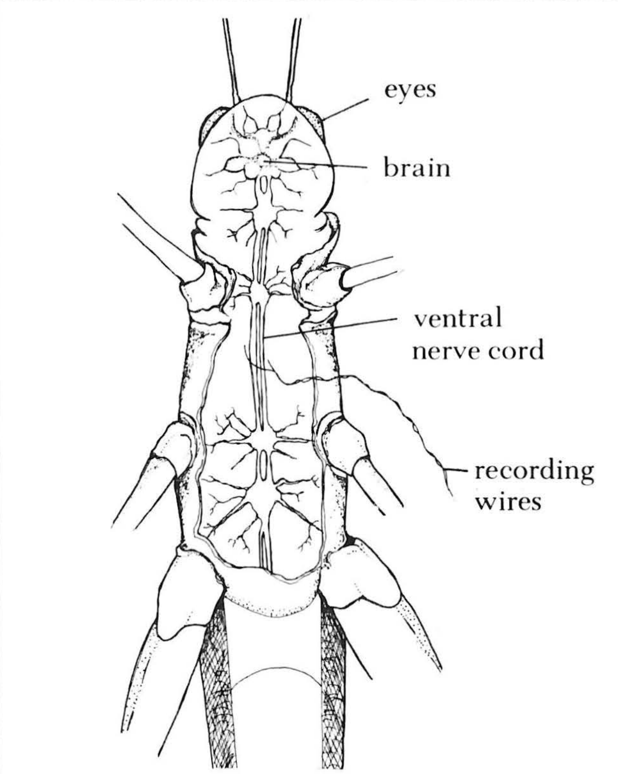
The exhibit is cylindrical in shape, being built out of sections of unwaxed cardboard cement form tube. Two cylinders of different diameters are used, the smaller one on top of the larger

note-overhead spots needed



one, creating a step for small children. The graphics are attached to a curved wooden backing which extends 180 degrees around the top of the exhibit and also acts as a barrier to block some of the outside "museum" stimuli the grasshopper would otherwise receive. Two 30 watt spotlamps are mounted above the top of the exhibit to illuminate the grasshopper. The grasshopper is enclosed in a plastic dome 12" in diameter which forms its "cage". A wire screen has been placed under the grasshopper's cage to act as an electrical shield and ground plane for the grasshopper to rest on. The oscilloscope is mounted inside the





cutaway diagram of the position of the wires

exhibit with its screen pointing up through a hole in the top of the table inside of the grasshopper's enclosure. The oscilloscope also serves to keep the grasshopper warm (which is necessary for its health!). The grasshopper has wire electrodes implanted along its ventral nerve cord. The wire used is .003" to .005" teflon coated stainless steel wire (available from Cooner Sales, Chatsworth, California. Stock #AS765-40). The wires from the grasshopper are connected to a Grass Instruments P15 Preamplifier, and the output of the preamp is hooked up to the oscilloscope and an audio amplifier. The signals from the grasshopper are in the range of 50 microvolts and the preamp passes only signals between 300 and 10000 Hz.

For information on preparing the grasshopper, please call or write the Exploratorium.

Critique and Speculation

This exhibit can be set up in a multitude of ways and ours has worked but is by no means the only physical arrangement possible. It would be easier for small children and people in wheelchairs to see the oscilloscope if it were mounted with its screen facing forward. Any suitable biological preamp and audio amplifier can be substituted for the ones we use. The exhibit works better in the morning before the grasshopper has been over-stimulated and habituated to the hectic pace of the museum. We had to obtain a permit to raise this species of grasshopper in California since it is an agricultural pest. Check with your local agricultural department for details.

Additions and Changes (1990)

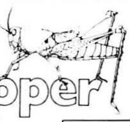
Since we wrote this recipe, the exhibit has been completely rebuilt. In the new version of the exhibit, we mounted the oscilloscope with its screen facing forward, which is easier on the oscilloscope as well as more convenient for visitors.

Related Exploratorium Exhibits

Language of Nerve Cells
Cheshire Cat
Crayfish Eye's Response to Light

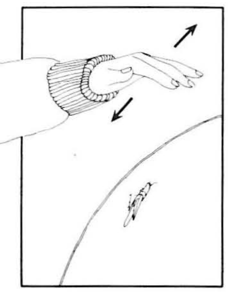
Exploratorium Exhibit Graphics

Watchful Grasshopper



Visual systems in most animals (including people) are very sensitive to moving objects. Specialized nerve cells detect movement.

To do and notice:



Hold still, wait, and then move your hand to a place where you think the grasshopper can see it. Stop, Try another spot.

As you move watch the oscilloscope and listen to the clicking sounds.

Notice that any movements, even those which are far away, or your own movements in reading this sign,cause the oscilloscope to produce more vertical spikes. The clicking sounds also become louder.

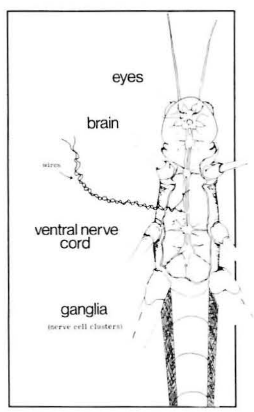
Try repeating the same movements a few times in a row. Notice that the activity of the oscilloscope and the clicking sounds gradually decrease.

Preparing the exhibit:

In an operation which does not hurt or permanently injure the grasshopper, two small recording wires are inserted into the thorax on the underside of the grasshopper. These wires are placed close to the grasshopper's ventral nerve cord.

Through these recording wires, sensitive amplification equipment detects specific nerve cell signals that travel from the animal's visual center (in the head) to a nerve cell in the thorax which controls jumping behavior. These amplified signals are displayed on the oscilloscope and can be heard as clicking sounds.

At the end of the day the grasshopper is returned to the colony. The recording wires usually wear out after about two weeks, and either fall out or are removed. Electroded grasshoppers show no behavioral changes.



What is going on:

In all animals, including man, certain visual nerve cells are stimulated by movement. In the grasshopper, the nerve cells which detect movement are very large. Therefore, any activity from the cells is easy to record.

When you move your hand over the dome, the motion-detecting cells of the grasshopper's brain are stimulated, and there is an increase in electrical activity. Recording wires implanted near the grasshopper's ventral nerve cord detect this increase and you see a large spike appear on the oscilloscope. The large spikes, and the accompanying clicking sounds, record visual stimulation. The small spikes record the firing of other nerve cells in the grasshopper's body.

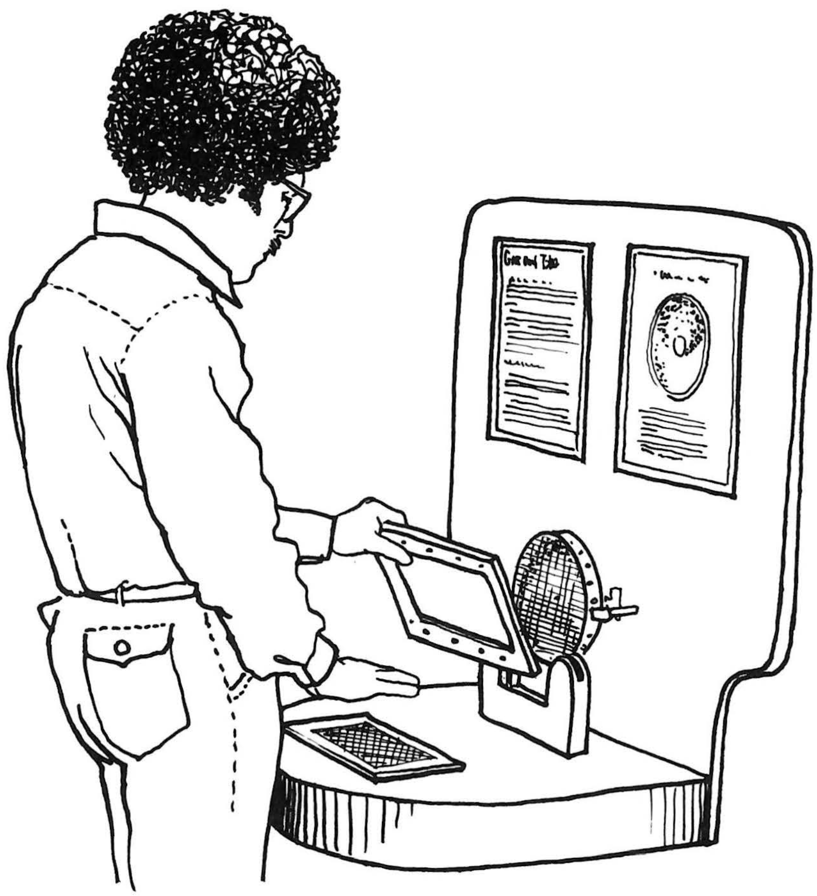
When you move your hand repeatedly, the animal tires, and the motion-detecting cells stop responding to your movements. Repeated movements simulate a situation that is no longer threatening to the grasshopper, such as a blade of grass being blown by the wind.

Related Exhibits:
LANGUAGE OF NERVE CELLS, here in the Animal Behavior section, and Vision exhibits upstairs on the mezzanine, including MOTION DETECTOR.

Illustrations Susan Schwartzenberg

Recipe No. 125

Give And Take

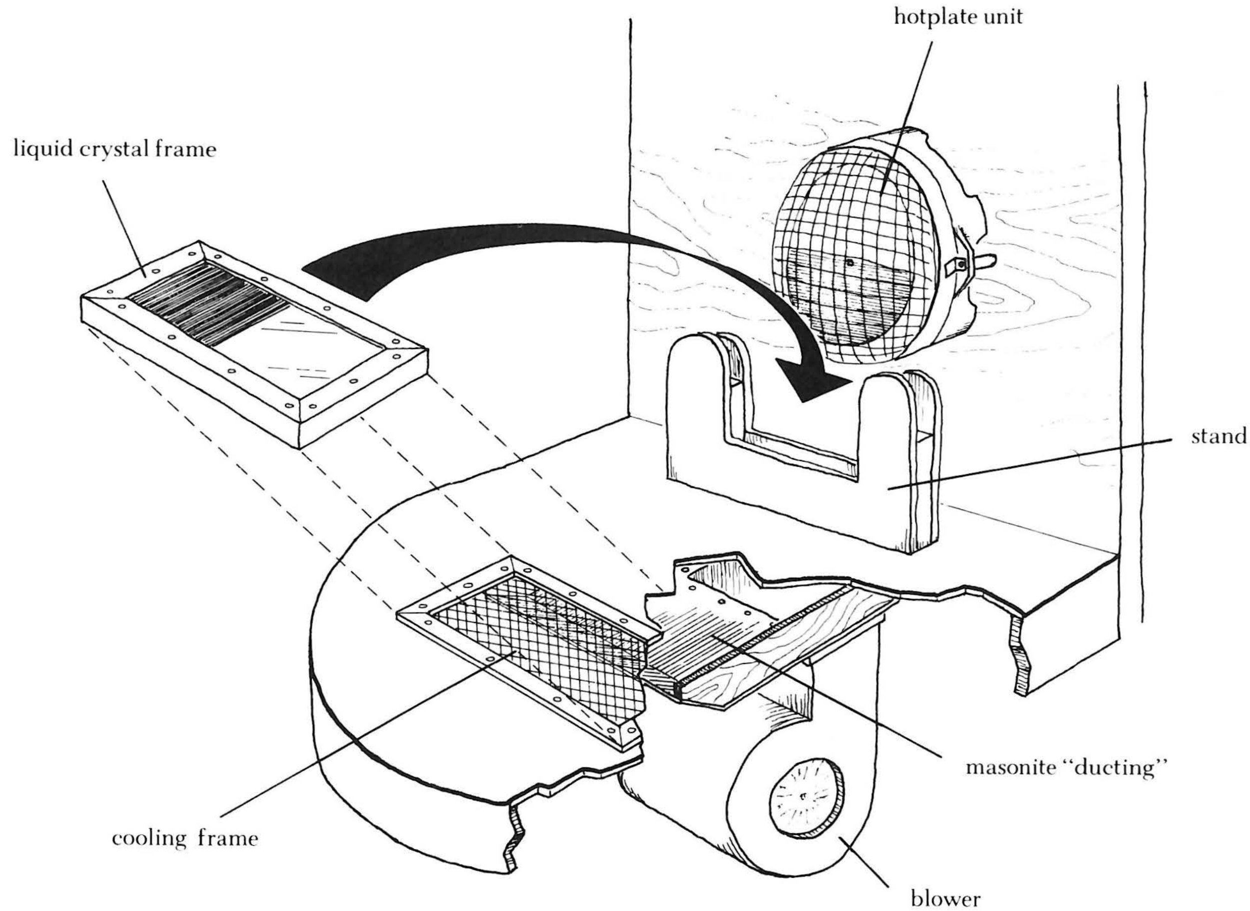


Description

This exhibit demonstrates that good emitters (givers) of heat are good absorbers (takers) of heat. The visitor places his/her hand near a hotplate on top of which is a piece of metal with one side painted black and the other side polished to a high shine. It is noticed that the black surface gives off more heat than the silver surface. A piece of heat sensitive liquid crystal material, on the back of which is glued a similar piece of thin silver/black metal, is placed in front of the hotplate. It is noticed that the black painted portion absorbes more heat by the changing color of the liquid crystal.

Construction

This exhibit is very simple to construct. The hotplate is of the common variety found in many appliance stores. We stepped down the voltage to the hotplate to 37 volts with a transformer (Any voltage close to this will work). This keeps the plate at a reasonable temperature. The thermostat in the hotplate was removed to allow the hotplate to remain on constantly. A thin piece of stainless steel is cut into a circle, polished, and one half painted with flat black spray paint. This plate is bolted through an existing hole in the center of the hotplate. Over the hotplate is placed a screen cover to keep people from burning themselves.



This cover is made by gluing the screen (1/4" holes) with green structural epoxy into a 1" slice of aluminum tube big enough to cover the hotplate. This whole assembly is then bolted onto the backboard of the exhibit (which also holds the graphics). The wires are routed along the back of the exhibit inside of split PVC pipe to the transformer beneath the exhibit table.

The table is made of plywood and covered with black formica for durability. The transformer is mounted under the table along with a blower used to cool the liquid crystals after use. The air from the blower is directed through a rectangular hole in the table top by masonite "ducting". Note that the air system only blows air AT the opening and is not a closed system which would cause the liquid crystal frame to be blown off of the table! Over the hole is mounted an aluminum frame which holds the liquid crystals in place while cooling, and a screen which keeps the liquid crystal frame from dropping through the hole. A stand made of aluminum to hold the liquid crystal frame in front of the hotplate is bolted to the top of the table.

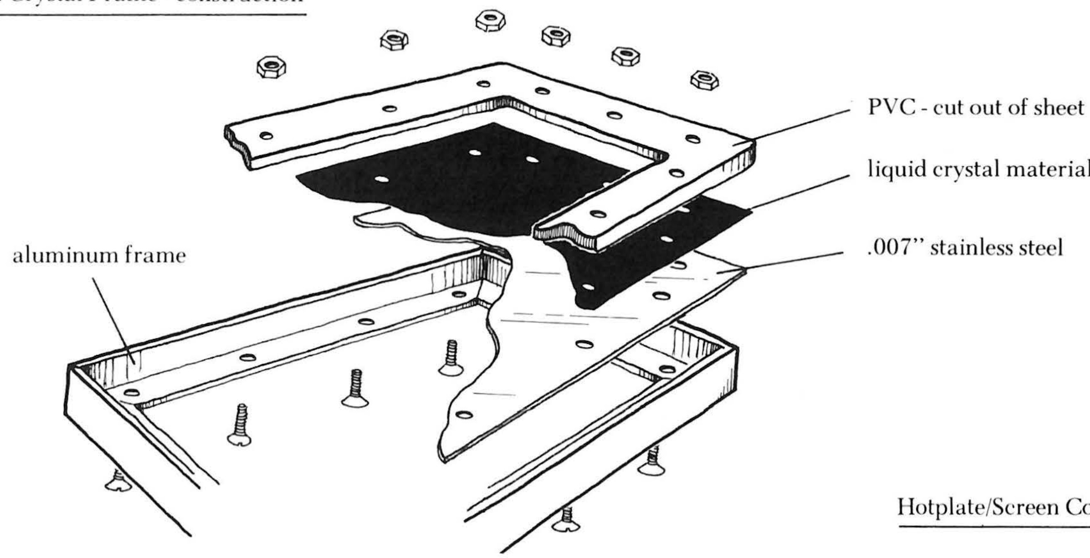
The liquid crystal frame consists of the parts shown in the diagram. The liquid crystal material is glued to the .007" stainless steel shim stock with contact cement. The liquid crystal material is available from:

Davis Liquid Crystals, Inc.
14722 Wicks Blvd.
San Leandro, CA 94577
(415) 351-2295

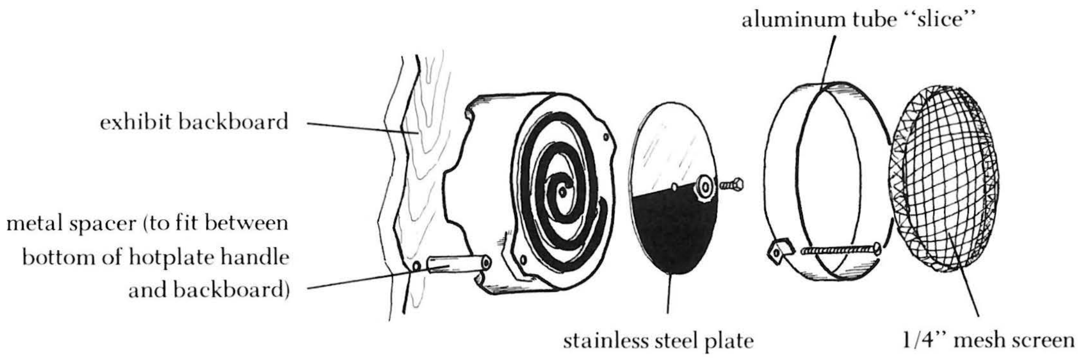
Critique and Speculation

If the shim stock is too thin, the material will be pushed in and destroyed. If the shim stock is too thick, heat will not be transmitted through it fast enough (stainless steel has poor

Liquid Crystal Frame - construction



Hotplate/Screen Cover - Construction



heat conductivity). One must find a happy medium and .007" shim stock is working for us (.001" didn't).

Additions and Changes (1990)

The orientation of the black paint on the hot plate with respect to the black paint on the panel is important. In our exhibit, the bottom half of the hot plate is black and the left half of the panel is black. When the panel is held up to the hot plate, the visitor can see every possible combination of emitters and receivers.

Related Exploratorium Exhibits

HEAT RADIATION

Hot Spot
Low Frequency Light

Exploratorium Exhibit Graphics

To do and notice:

Hold your hand in front of the hot plate, one half of which is black and the other half shiny. Notice that the black half radiates more heat to your hand than the shiny half.

Hold the frame, which has metal on one side and heat sensitive liquid crystal material on the other, in front of the hot plate with the heat sensitive side toward you.

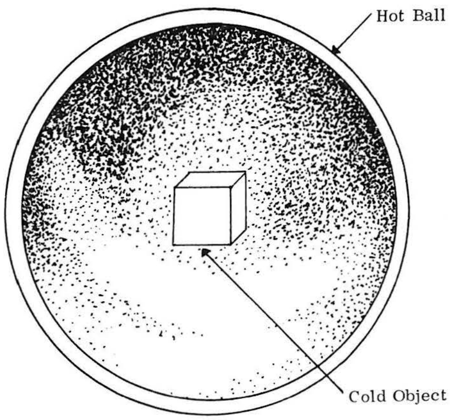
Notice that if you have the black half of the frame facing the black part of the plate it heats more quickly than any other arrangement, for example, shiny against shiny or black against shiny.

What is going on:

This exhibit shows that good absorbers (takers) of heat, i.e. black objects, are good emitters (givers) of heat, and that poor absorbers, i.e. shiny mirrors, are also poor emitters of heat.

Hot coffee in a thermos would cool off much more quickly if the walls of the insides of the thermos bottle weren't shiny. And a car with a black top sitting in the sun heats up much more quickly than a car with a white top.

A "thought experiment"



The hot hollow ball will radiate to the cool object at its center, gradually warming it up. If the object did not then radiate back as much heat as it absorbed, it would get hotter and hotter and hotter, which does not make sense.

One must therefore conclude that a good absorber, such as a fuzzy black object, is also a good emitter of heat, and that a poor absorber, such as a white or shiny object, is also a poor emitter of heat.

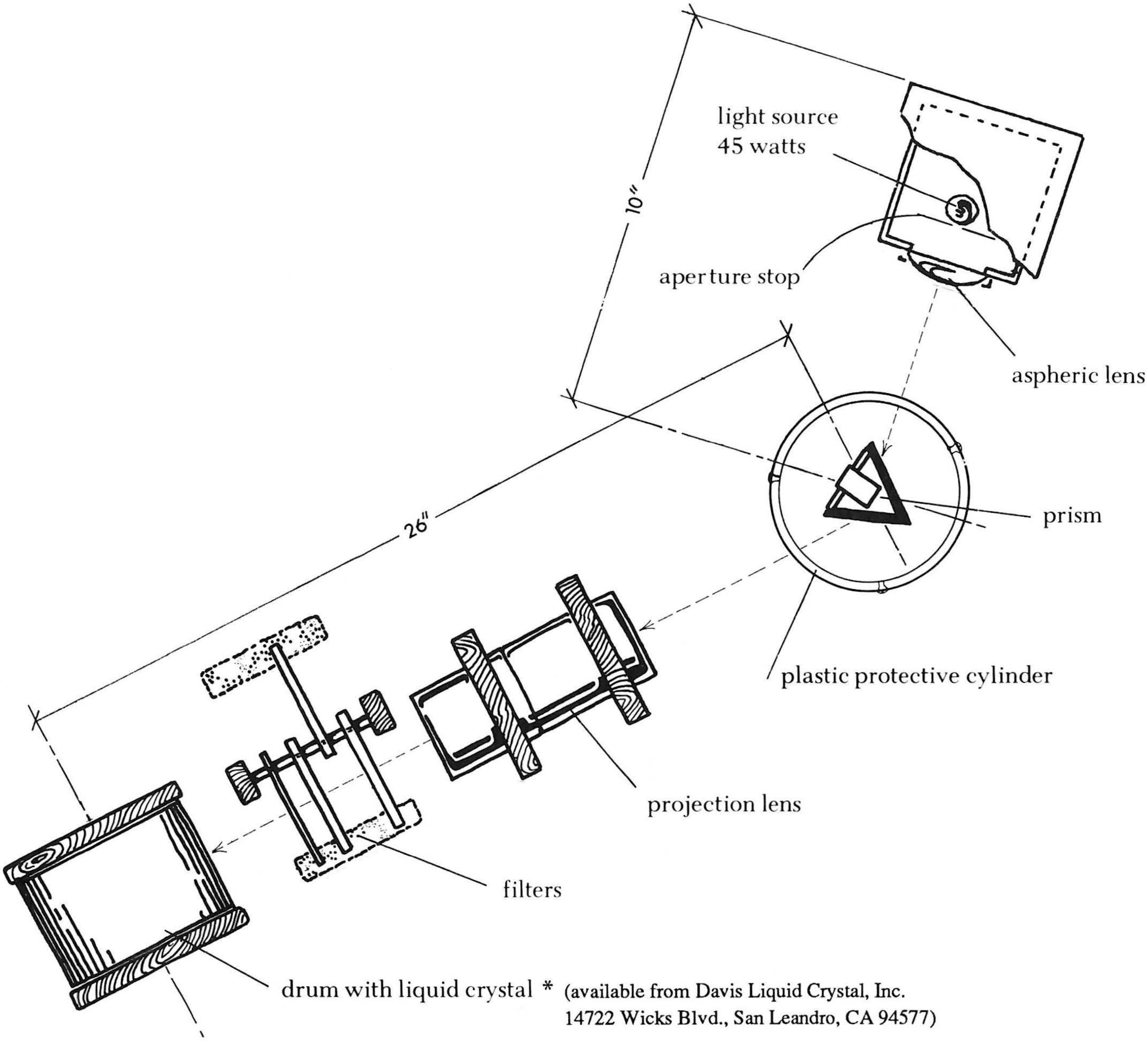
Low Frequency Light

Description

White light is broken up into its component colors and the spectrum is cast upon a liquid crystal screen. This material changes color when heated. Beyond the red portion of the spectrum the liquid crystal material changes color, because the infrared light (heat) is of a longer wavelength than that of red and is invisible to the unaided eye. Filters can be placed in the spectrum to see how they affect the infrared and visible portions of the spectrum. One of these filters lets through only the infrared and blocks all visible light while another lets through all visible light but blocks the infrared.

Construction

The exhibit consists of five basic components, bolted down to a black formica® covered table on welded aluminum legs. Flat black formica® was chosen to



* (available from Davis Liquid Crystal, Inc. 14722 Wicks Blvd., San Leandro, CA 94577)

increase contrast in the spectrum and because of its durability. The five components are: the light source, prism and enclosure, focusing lens, filters and holder, and liquid crystal drum.

The light source is a welded aluminum box and cover with a 6.6 amp tungsten-halogen lamp mounted vertically behind a hole cut in the side of the box. A condenser lens (aspheric, focal length 1.5", 2" diam.) inserts from the front of the box into a step machined in the hole, and a ring holds the lens in place. A small amount of front/back adjustment in the lamp mounting is needed for focusing. A "barn door" (see sketch) type of aperture stop is placed in front of the lamp to cut out stray light which would otherwise detract from the spectrum.

The prism is a 60 degree high dispersion, heavy flint glass prism, with 60x60 mm. sides (index of refraction = 1.7343) purchased from:

Klinger Scientific
83-45 Parsons Blvd.
Jamaica, New York 11432
tel: (212) 657-0335

catalog number 336679 (1978 cost $194). The prism is mounted in a triangular

"plate" and held in place with a rubber tipped top piece. This assembly is mounted on a post to a heavy aluminum plate and the entire assembly covered with a plexiglass cylinder and top. Two holes are drilled into the cylinder to allow the light to enter and exit unimpeded.

The projection lens is mounted to a wooden block at a height and position which focuses the spectrum on the liquid crystal drum. Our lens is an old overhead projector lens with a focal length of about 14".

Four filters are provided for experimentation (red, blue, IR transparent, IR absorbing). All are 4x4" and drilled near one corner. A brass bushing is glued through the hole with silicone seal and the filters placed on a steel rod mounted in wood blocks to the table. We found it necessary to firmly attach the filters to the table or else they would disappear. The filters can be pivoted up into the spectrum when desired. When released, their fall is cushioned by strips of foam rubber attached to the table.

The liquid crystal screen was fashioned into a drum by wrapping the thin plastic sheet which contains the crystals around a piece of 6" diameter cardboard tube 6" wide and taping the ends down with clear tape. The sheet was taped to the drum with transfer tape that leaves only the adhesive behind when used. The drum has machined aluminum endcaps with pressed in Rulon bearings and a 3/8" shaft running through the drum and bearings into a wooden support. The light passes through 8 cm. of glass (condenser lens, prism, focusing lens) without suffering too much infrared absorption.

We have found that, in our environment, the prism must be held more firmly to the base plate than we had originally thought. To hold the prism down, a recessesed triangular plate, similar to the base plate was fashioned to fit over the top of the prism and secured with three long screws through the corners of the top plate into the base plate.

Additions and Changes (1990)

You can purchase the prism for this exhibit from:

Karl Lambrecht Corp.
4204 N. Lincoln Ave.
Chicago, IL 60618
(312) 472-5442

Heavy flint prism (60mm X 60mm 60°)
catalog # 336679 $280 (1990 price)

You can also purchase the prism, the condenser lens, and the projection lens from:

Melles Griot
1770 Kettering St.
Irvine, CA 92714
(714) 261-5600

Heavy flint prism (60mm X 60mm 60°)
catalog # 01-PEH-019; $277 (1989 price)
Plano-convex projection lens (300mm focal length; 95mm diameter) catalog #01-LPX-309
Aspheric Condenser Lens (50mm focal length; 75mm diameter) catalog # 01-LAG-023

Related Exploratorium Exhibits

Hot Spot
Heat Rays and Light Rays
Hot Light

To do and notice:

Rotate the drum a little, then stop to place a fresh piece of liquid crystal material into the colored spectrum.

Wait and watch the temperature sensitive liquid crystal material change color when the heat of infrared warms it up.

Try various colored filters in the light beam to see how they affect the spectrum. You may have to wait in some cases to see the heating effect of the infrared beyond the red.

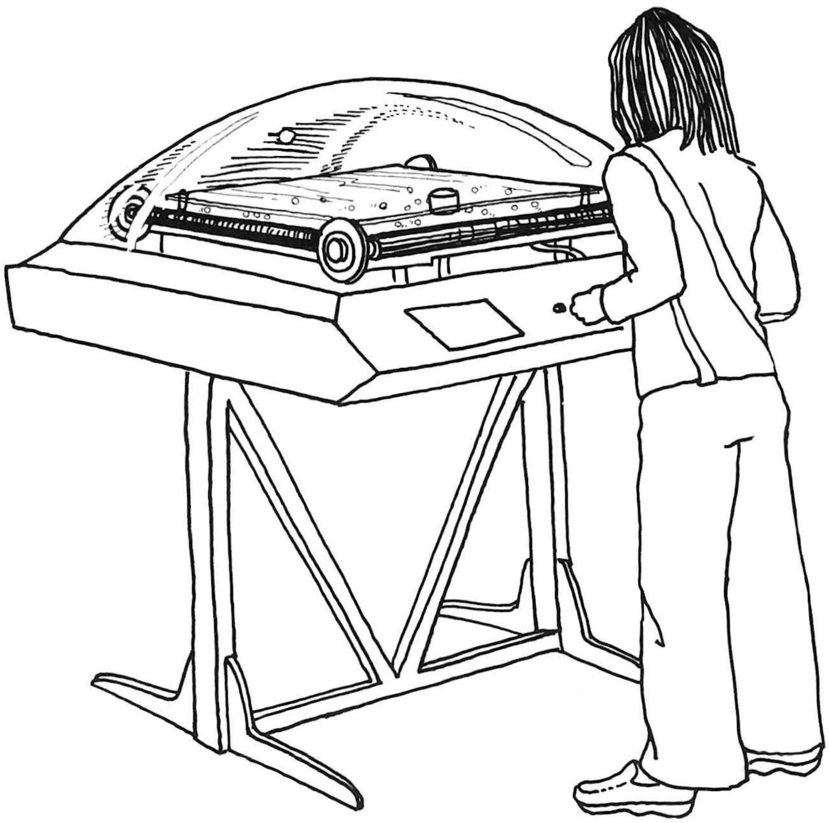
Liquid crystal material donated by Liquid Crystal Technology, Inc., Pleasanton, California

What is going on:

The white light is broken up into its component colors by the prism. The more slowly vibrating red light is bent less by the prism than is the more rapidly vibrating blue light. The even slower vibrating infrared is bent less than the red. The slower the rate of vibration, the longer the wave length of the light.

In a glowing piece of metal (filament) the violent dance of the electrons produces electromagnetic waves. When the frequency of the waves is high enough, but not too high, our eyes are sensitive to them, and we call them visible light. Infrared, like ultraviolet, is not visible to the unaided eye. Much of the energy of sunlight arrives as infrared and makes you feel warm. The ultraviolet is invisible and can give you the most severe sunburn.

Brownian Motion Model (Molecular Buffeting)

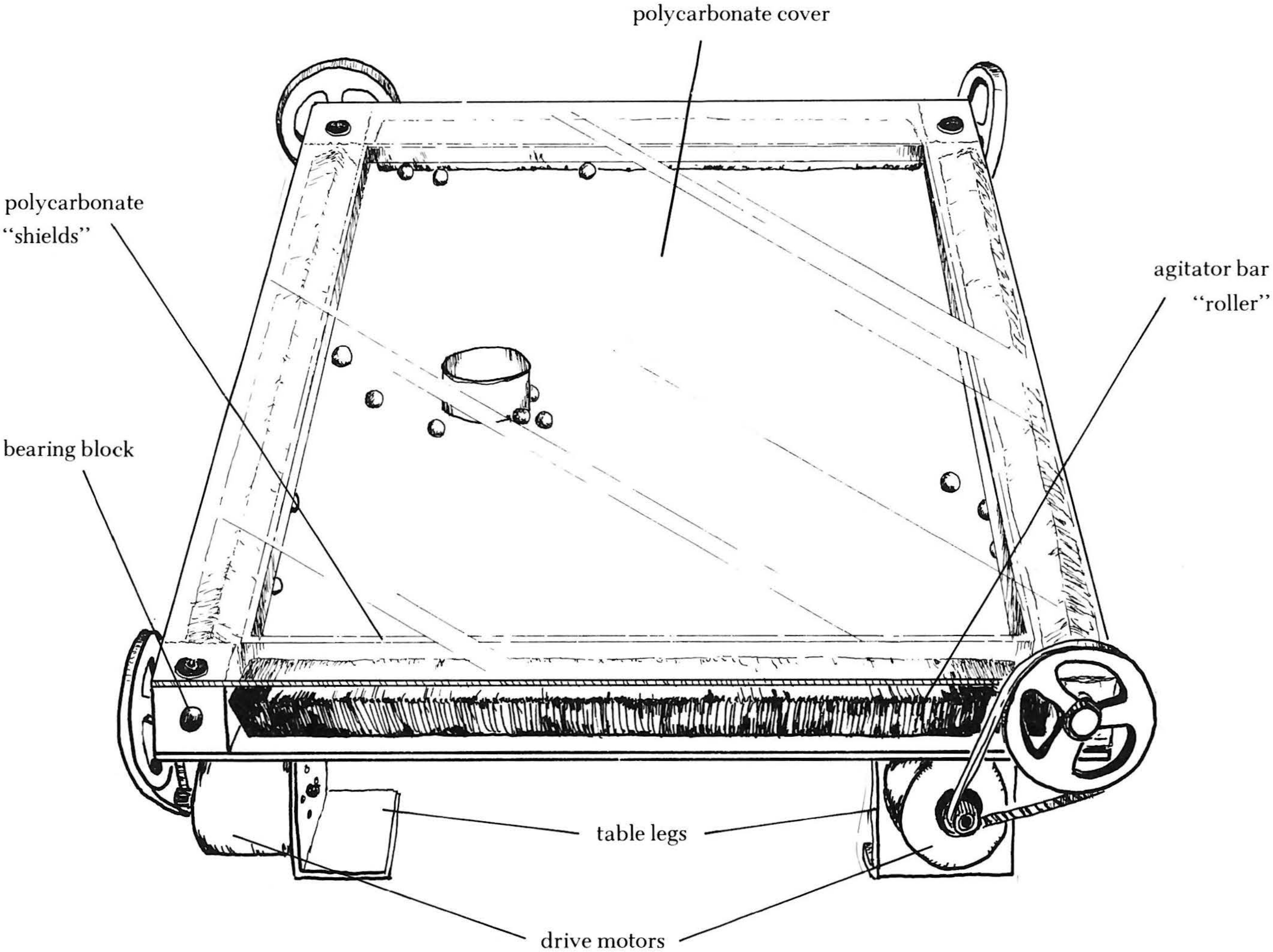


Description

Brownian motion is modeled in this exhibit. Ball bearings representing water molecules are agitated ("heated") by rotating square bars into an apparently random motion on a 2x2 foot surface. A piece of PVC pipe representing a small drop of oil in the "water" is bumped around by the "molecules", and does a random dance analagous to Brownian motion. Actual Brownian motion can be viewed in a companion exhibit, **Brownian Motion.** The model allows the parameters of operation such as the amount of agitation (temperature) and condensation (stopping one roller) to be played with.

Construction

The exhibit is constructed on a base of 1/2" aluminum plate 27"x27". The four agitator bars are made of 1" square steel tubing 22" long with .062" thick walls. A 1" cube is welded onto each end of the tubes and drilled with a 3/8" hole to accept the 3/8" hardened steel shaft. Before drilling, the excess weld material is removed with a sander, leaving the surface flush with the tube. The ends are then drilled undersize and then reamed to exactly 3/8". The hole must be concentric with the axis of the roller on each end or misalignment of the bearings will result. The steel shaft is inserted into the hole (one for each



end) by heating the roller end with a torch to expand the hole while cooling the shaft in liquid nitrogen, and then quickly inserting the rod in the hole (you only get one chance!). 5/8" of shaft protrudes from one end and 3" from the other. The rollers have a sheet of 1/16" rubber contact cemented to their surfaces to protect the roller and ball bearings and to reduce the noise. Four bearing blocks are drilled to accept the Rulon bearings for the 3/8" shaft (bearing OD is 5/8"). These bearings are pressed into the blocks up to their 1/8" thick shoulder which acts as a thrust washer. To obtain smooth operation and optimum alignment, it was necessary to place shims under the bearing blocks while tightening the four hold down screws while rotating the bars.

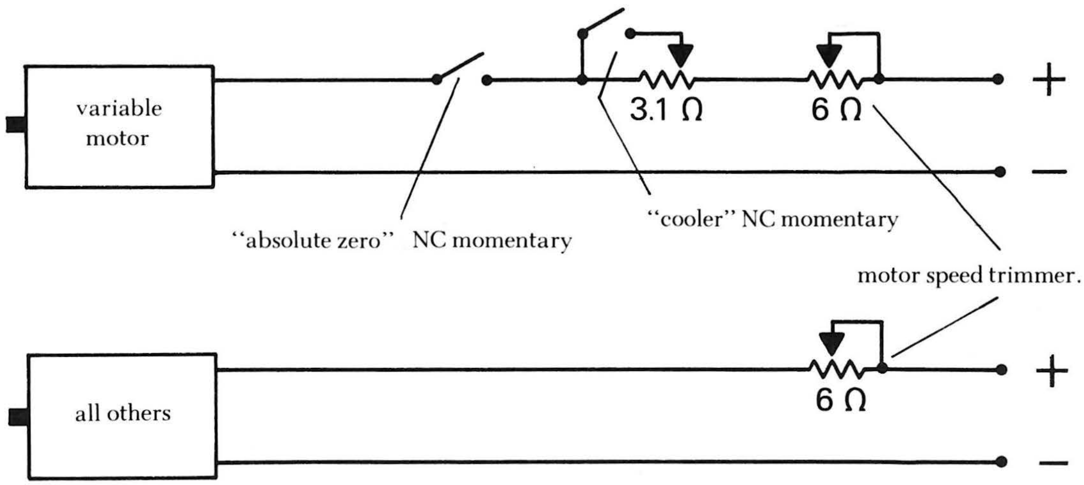
Covering the top of the apparatus is a sheet of polycarbonate plastic to keep the balls from jumping out of the exhibit. Shields are glued on the underside of this sheet near the rollers to keep the balls from getting caught between the top of the roller and the cover. The cover is held on with 3M snaps.

The rollers are each driven by a 24 VDC motor via posidrive pulleys and belts.

Motor pulley:	20XL037
Roller pulley:	70XL037
Belt:	200XL037

The motors we used are 7500 RPM, and

schematic



a reduction in the pulleys was necessary. The motors are mounted on the legs of the table which can be moved and then bolted to the table to allow tension adjustment in the belts.

The external controls allow the user to adjust the speed of all rollers, stop one roller, and slow one roller. Internal controls are minimum and maximum speed of the rollers and the speed of the slow roller when selected. These are wired as shown. We used a Hewlett Packard 6264B power supply for which a cheaper substitute could easily be found. It supplies about 8 volts at 8 amps to run the 24 volt motors (we don't use them at full speed).

The exhibit is enclosed in a wooden box with a hinged plexiglas® skylight dome cover on an aluminum frame 42" square. Fan ventilation is provided since the motors can get quite warm on a hot day.

Critique and Speculation

Once the bearing blocks are lined up properly the exhibit runs with very little attention except for an occasional cleaning on the plexiglass dome both inside and out. The rubber on the rollers will eventually have to be replaced although ours have been running for more than a year now on the original set with very little wear.

We have replaced the steel ball-bearings in this exhibit with nylon balls. The steel bearings tend to be hard on the exhibit. We kave left a few (maybe 5 to 10) steel bearings in the exhibit for interest.

Because the nylon balls are much lighter, a lighter "oil drop" had to be substituted. The PVC tube has been replaced with the bottom of a styrofoam cup (upside-down.) This cup bottom is replaced more often than the trouble free PVC pipe.

Instead of using 1/16" rubber sheet glued to the square steel rollers we have switched to using pieces of bicycle inner-tube. This is much easier to apply and maintain.

Additions and Changes (1990)

After a number of years of use, the aluminum plate in this exhibit eventually warped. We have switched to nylon balls, which we believe will prevent the plate from warping again.

Related Exploratorium Exhibits

KINETIC THEORY OF GASES

Gas Model
Glass Bicycle Pump
Brownian Motion (Molecular Buffeting)

The hotter a substance the more energy there is in the motion of the molecules. Here the ball bearings represent the molecules.

To do and notice:

Change the speed of the rotating bars, and watch the ball bearings get "hotter" or "colder." The faster their average motion the higher the "Temperature."

Notice that the large white object is being buffeted on all sides and is moved around in a random fashion by these collisions. This white object represents a speck of something much larger than a molecule.

Each of the rotating bars represents a heater.

Push the button that stops the bar on the far side from rotating. Notice that the molecules do not rebound with as much energy and instead clump together like the liquid droplets on the outside of a cold glass of water.

Look through the microscope next to this exhibit and notice the tiny jittering specks, each one of which corresponds to the white object being moved by the steel ball bearings.

Historical Significance

Grains of pollen suspended in water performing a strange erratic dance that never stopped was a fact noticed by English botanist Robert Brown in 1827 while peering into his microscope. At first Brown thought that this motion was a sign of life. Upon repeating the experiment with other kinds of dust not derived from living things, he found that the same kind of motion occurred, so life was not necessary for the effect. Brownian motion remained a mystery until it was realized that the erratic dancing behavior of small particles could be explained by the molecular theory of matter. A very tiny particle that is being struck on all sides by small numbers of invisible molecules can temporarily get out of balance; the invisible molecules will then give the particle an extra push in one direction which produces the motion that can be seen through a microscope.

The explanation of Brownian motion was the last crucial step in verifying the molecular theory of matter. At least since the times of the ancient Greeks there have been people who thought that matter was composed of very small indivisible particles or molecules that could not be broken into any smaller pieces.

Physicists, including Baltzmann and Maxwell and many chemists made great theoretical progress by assuming without proof, that molecules existed, but many other people still remained skeptical.

But even though great strides in physics and chemistry were made during the 18th and 19th century, only indirect arguments led to the conclusion that matter consisted of discreet particles, rather than of a continuous smear of matter.

The matter was settled in 1908 with direct experiments performed by Jean-Babtost Perrin (1870-1942). Perrin plotted the actual moments of the "Brownian Dance" and compared these movements to calculations which Albert Einstein had made in 1905. Einstein assumed that the tiny pollen particles that Brown had observed were being buffeted by water molecules that were agitated because of their thermal motion. He calculated what motion of the pollen would be produced by the random buffeting of water molecules. Perrin's experimental results agreed with Einstein's calculations in 1928. Perrin received the Nobel prize in Physics for this work.

Today we have many other ways of showing that matter is made of individual particles. We now know, for example, that the electrically charged particles investigated between 1895 and 1911 by J.J. Thomson, Rutherford, Wilson and Millikan and others were really negatively and positively charged fragments of atoms. Cloud chambers and spark chambers now allow us to see the paths of single particles of matter. But even today, although we have evidence of atoms and molecules we do not have evidence that there are "indivisible particles."

Brownian Motion (Molecular Buffeting)

Description

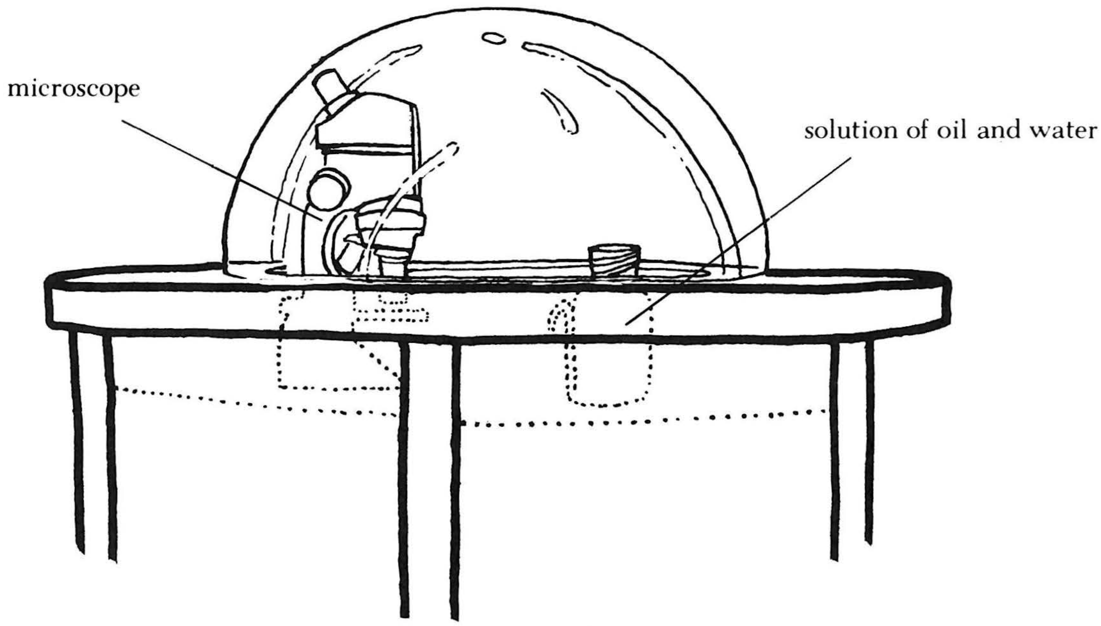
The Brownian motion of small oil droplets in water is observed through a normal light microscope. The motion is seen as a jiggling of many tiny white spots against the dark background. If the drop is smaller, it is observed to move more violently as it is hit on all sides by the water molecules.

Construction

This is a very simple exhibit, the only critical component being the water soluble oil used as the emulsion under the microscope. We use a surplus field microscope made by American Optical (any good microscope will do). The microscope must have a dark field illuminator since the oil is essentially clear drops in a clear liquid and would be invisible under normal illumination.

The microscope is screwed down to the top of a pedestal under a hinged cover with a 12" plexiglas® hemisphere over it. A step is provided for small children in front of the exhibit. The eyepiece of the microscope is perpendicular to and almost touching the dome to allow people to look though the dome into the microscope. This keeps the microscope from being vandalized or stolen. To work properly the eyepiece must be of the extended pupil type to allow people with glasses to view the spectacle.

The solution of oil and water was made from Dromus B oil,



a licensed product of the Shell Oil Company. To find a local distributor of the oil, check in the yellow pages under Oils-Lubricating, and look under Shell Oil.

The oil is mixed with 15 parts water which forms an emulsion with oil drops averaging about 1 micron in diameter suspended in the water. This emulsion is then placed on a microscope slide and covered with a large cover slip (the larger the cover slip, the longer the slide will last) and placed under the microscope. Only a small drop is needed on the slide. We find that a magnification of about 450x is optimal.

Critique and Speculation

The water in the slide slowly evaporates and the slide must be replaced at least once a week. Various methods of sealing the slide have been attempted (bee's wax, finger nail polish) but none have been successful.

The outside of the dome tends to become dirty (greasy) and must be cleaned often.

Related Exploratorium Exhibits

ATOMS, MOLECULES AND THE NATURE OF TEMPERATURE

Gas Model

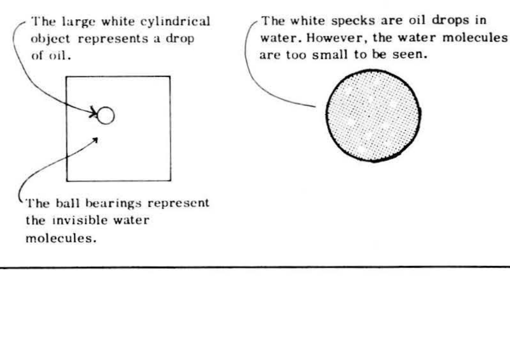
Brownian Motion Model (Molecular Buffeting)

Exploratorium Exhibit Graphics

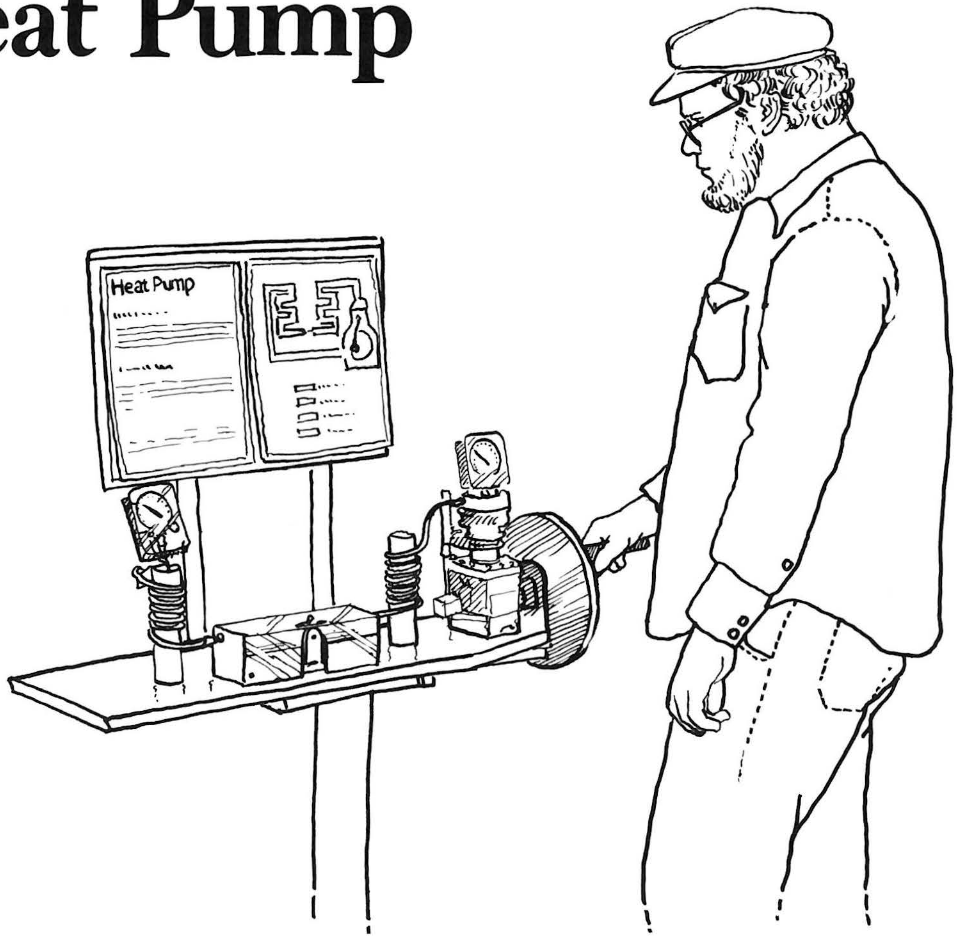
To do and notice:

Look into the microscope notice that the tiny drops of oil are knocked back and forth by the motion of the water molecules even though the water molecules are invisible.

The steel balls, in the exhibit to your right knock the white cylinder around in much the same way.



Heat Pump

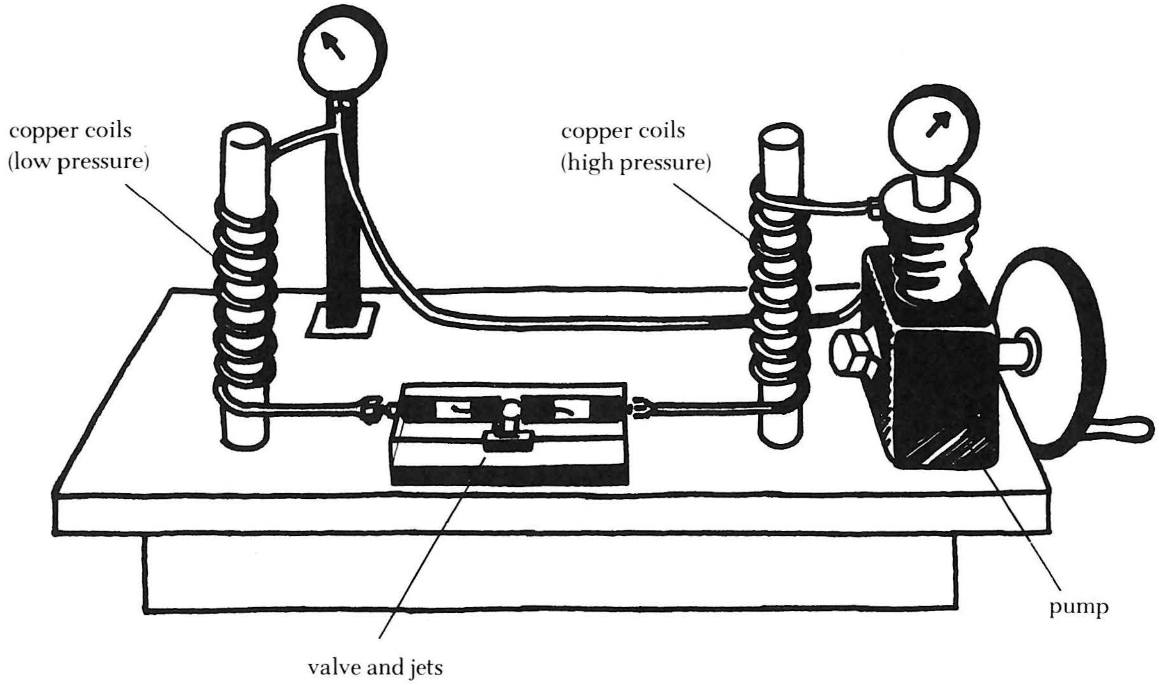


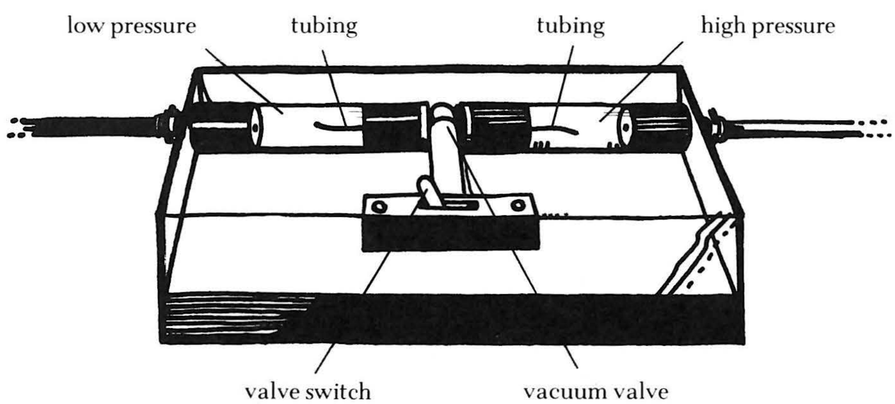
Description

The visitor turns a crank on a small compressor and feels coils of copper tubing hooked to the high and low pressure sides of the pump. As more work is done, the high pressure coil becomes warm to the touch and the low pressure coil becomes cold. Leakage from the high pressure side to the low pressure side can be regulated with a valve.

Construction

The central piece of equipment in this exhibit, the compressor, was taken from an old refrigeration unit. The newer types of compressors enclosed in a "can" are unsuitable since the drive shaft is inaccessible. A large heavy steel flywheel with a handle allows the visitor to crank the pump smoothly. An extra bearing and support for the drive shaft was added outside the pump to insure durability. The head on our pump was unacceptable because the high pressure outlet volume was too large allowing a large amount of freon® to condense there instead of in the high pressure coil. To remedy this, we machined a new head to the specifications necessary. Standard 1/4" copper tubing and fittings are used to construct the "plumbing". From the pump, the tubing is wrapped into a 6 or 7 turn coil about 1 1/2" in diameter around a piece of PVC pipe which is





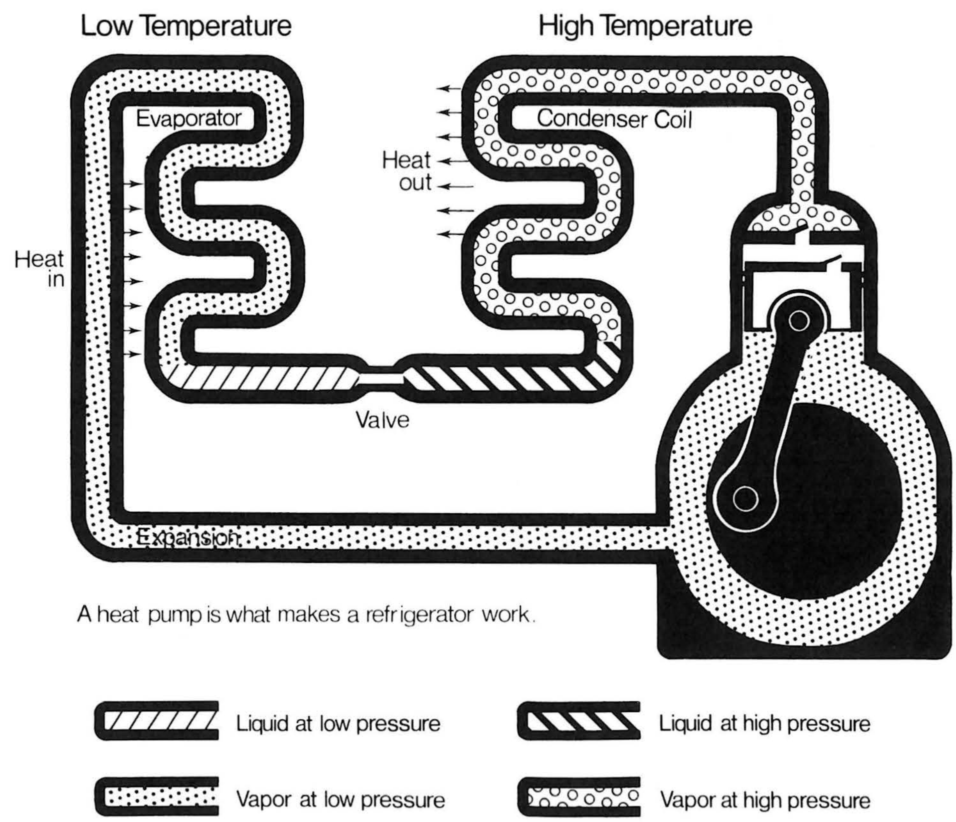
fastened to the table. This is done on both high and low pressure sides with a Nupro brand "H" series bellows sealed valve connecting the two sides. These valves are available from local suppliers with different fitting ends. Choose one appropriate for your needs. The input and output ports of the valve have small pieces of copper capillary tube soldered into them (see below). The valve was then connected to two Pyrex glass tubes with stainless steel copper tube fittings, machined to fit over the glass tube. The glass and fitting is glued together with vacuum epoxy. Since the valve only has to be "cracked" open, the valve knob is attached to a small lever which protrudes through the plexiglas box which surrounds the valve assembly. The small capillary tubes from the valve are each bent, the high pressure side down so that it is under and condensed freon®, and the low pressure side up so that it produces a visible spray.

The exhibit is built on top of a table with a heavily weighted base to prevent it from tipping over.

Related Exploratorium Exhibits

Glass Bicycle Pump
Air Track

Exploratorium Exhibit Graphics



A heat pump is what makes a refrigerator work.

Turning the crank pumps heat from the coil on the left to the one on the right.

To do and notice:

Notice the liquid which may be in the glass tubes.

Close valve and begin to turn the crank on your right.

Notice the liquid collect on the high pressure side of the valve and disappear on the low pressure side.

Feel the two coils. Notice that the coil on the low pressure side (left side) starts to cool and the coil on the high pressure side becomes warm.

Open the valve part way and notice the liquid spray into the low pressure tube.

Notice that the low pressure coil becomes colder and that if you keep pumping the high pressure tube becomes warmer.

What is going on:

Turning the crank operates a pump which compresses the refrigerant, a gas called Freon. The work done heats the gas which then passes into the high pressure coil. By giving off heat in this coil, it cools down to a temperature at which it condenses or liquifies. (This coil is usually known as the condenser or radiator coil.)

The liquid passes through the valve to the low pressure or evaporator coil, where it absorbs heat from the surroundings and evaporates to a gas or vapor. The vapor then goes to the pump, or compressor, where the cycle begins again.

Note that the low pressure coil cools below its surroundings, enabling heat to flow into it, and that high pressure coil gives off heat to its surroundings. The net result is that the work you do in turning the crank pumps heat from the left coil to the right one. This work that you put into the system is converted into heat and must also be given off by the hot coil.

You can heat your house with a heat pump by taking heat out of the cold ground, making the ground colder but the house warmer.

Historical Significance

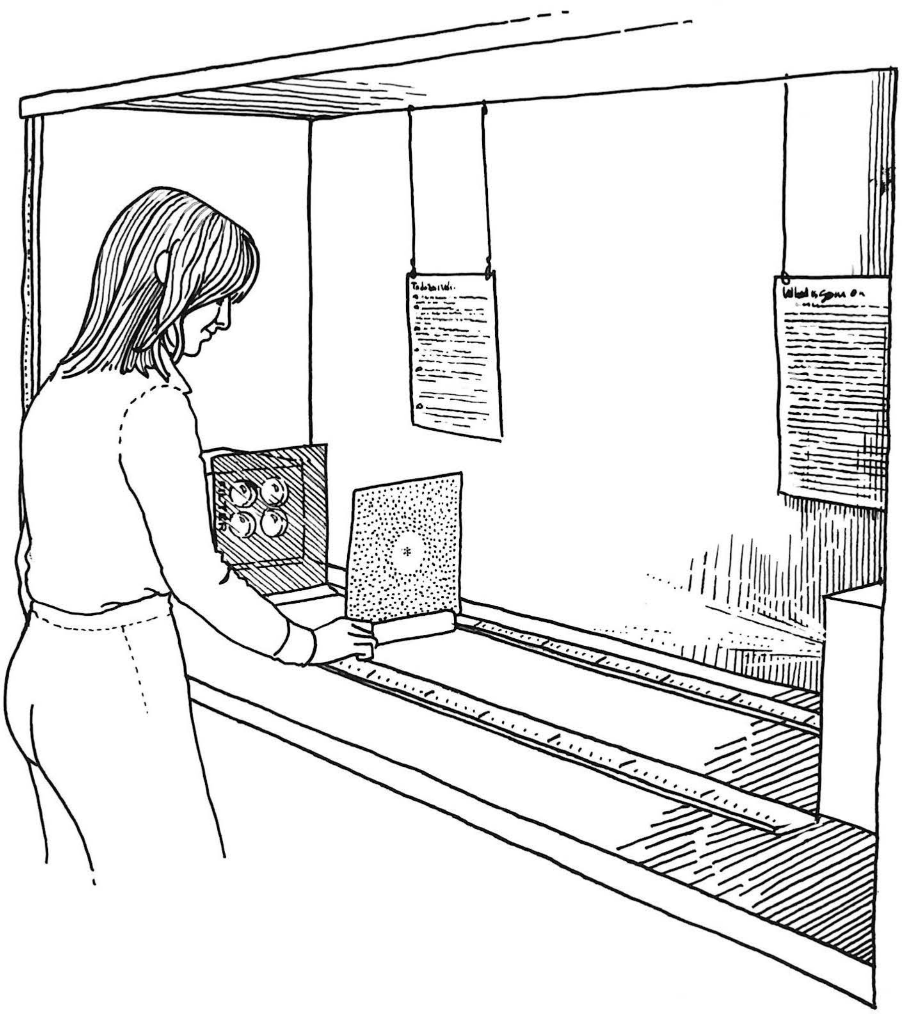
Sadi Carnot first suggested in 1812 that a heat pump was possible by reversing the cycle of a heat engine. He did not design a practical heat pump himself but used the idea of a reversed engine cycle as a heat pump to calculate the maximum efficiency that could be reached by an ideal heat engine.

The first practical heat engine was a steam driven water pump installed by Thomas Newcomen in an English coal mine in 1712. Though this engine was a vast improvement over the horse driven methods of raising water from the mines, it actually converted less than 1% of the energy of the coal burned into the useful work of lifting water. James Watt and others improved the steam engine so that by 1802 an engine was built that had an efficiency of about 6%. Today steam engines can be made with efficiencies of about 40%. Carnot asked the important question of just how efficient could an ideal (frictionless) engine be, and just what factors would be of most importance in designing a practical engine to approach the ideal efficiency?

Carnot realized that the heat entered an engine at a high temperature, left the engine at a low temperature, and produced some useful work. If the engine were ideal then this same amount of work could be used to drive the same engine backwards as a heat pump and heat the cooled steam back up to the original high temperature of the boiler.

The results of Carnot's thought experiment showed that the ideal efficiency of a heat engine would be increased if very high temperature steam were used. However the efficiency could never be 100% unless the condensed steam was discharged at the impossibly low temperature of -460° F. or absolute zero.

Grease Spot Photometer

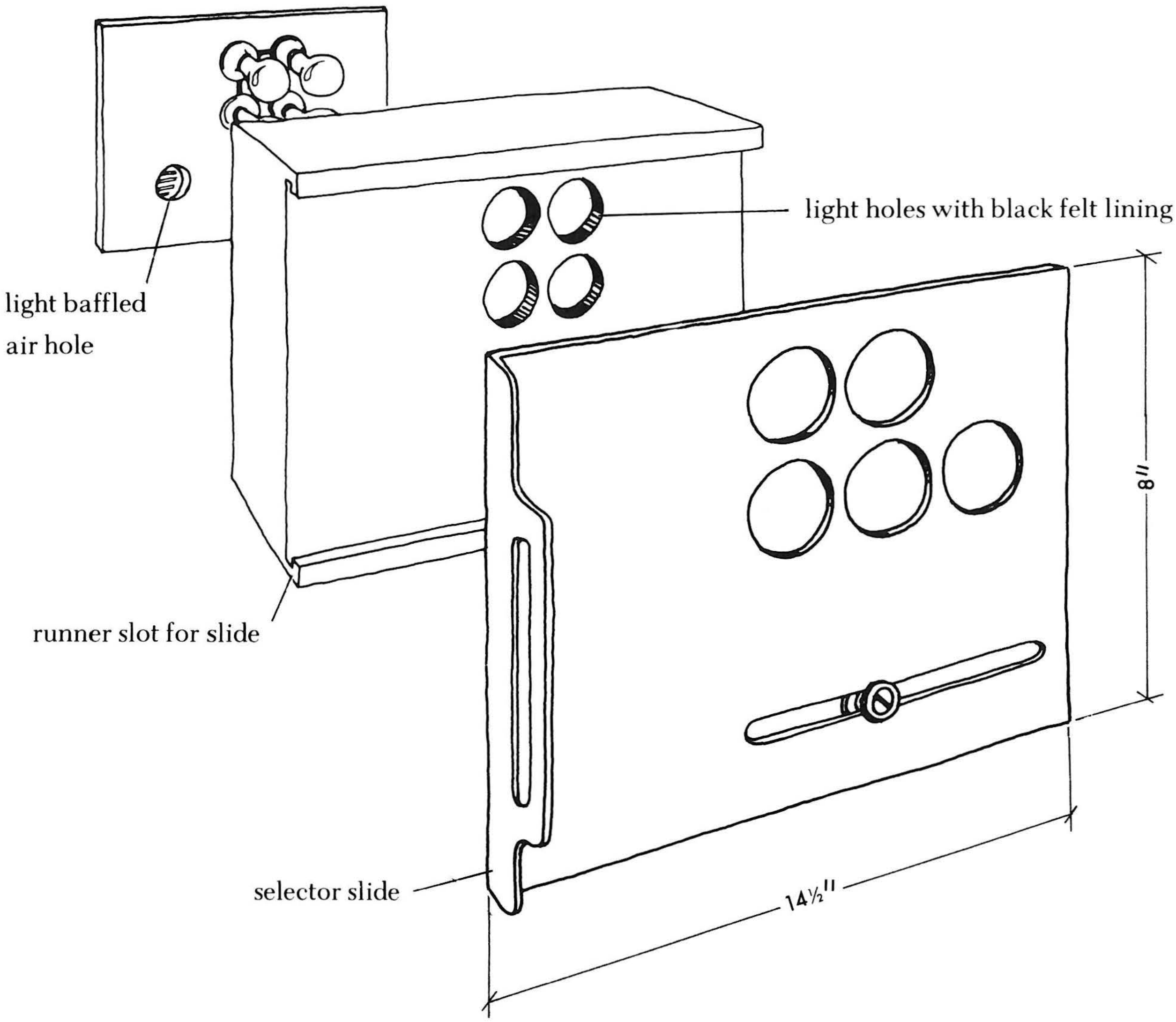


Description

Light of two different intensities can be compared using a measuring stick and a card with a grease spot in its center. The card can be placed at any point between the light sources. When the light falling on each side of the paper is equal, the translucent grease spot will disappear. By comparing the distances from the card to the light sources, the relative intensities of each can be determined. Extra lights can be covered or uncovered to further clarify the underlying principles of the exhibit. The effect of a smoked plexiglas® filter can also be explored. We fortunately found a filter which lets through 1/4 of the light.

Construction

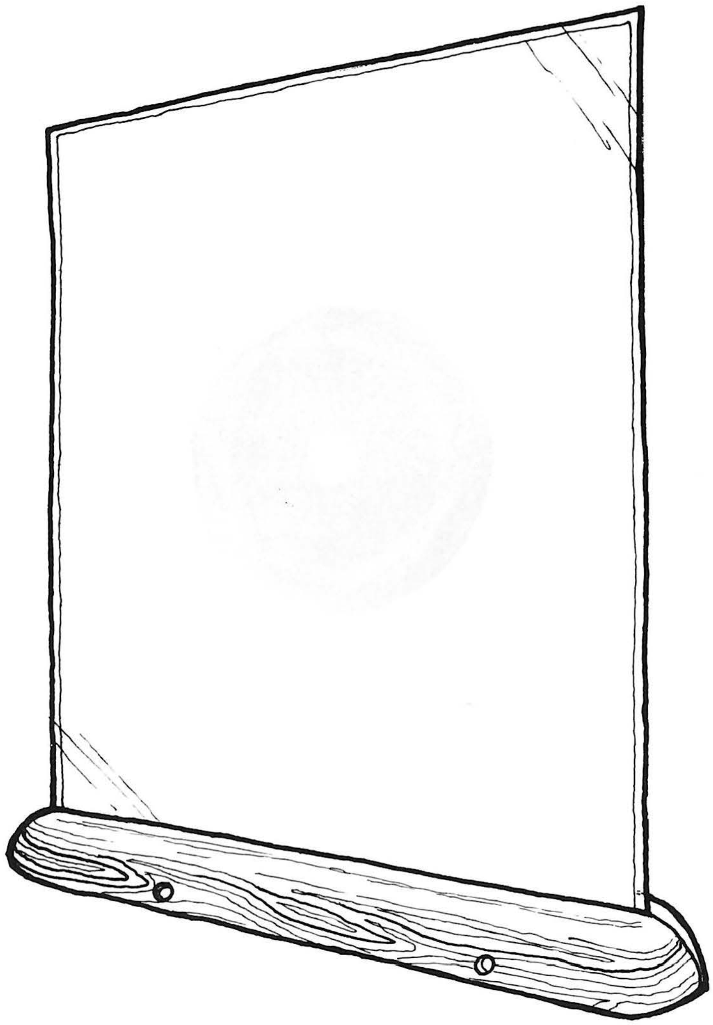
Construction of this exhibit is very straightforward. The frame is made of 1" square steel tubing with .062 wall thickness for ease of welding. Ends of the tube where people are likely to bump



their heads have had round caps welded over them. The height and depth of the exhibit allow for easy wheelchair access. The table is made of plywood covered with black carpeting purchased from an auto upholstery vendor (the only place we could find black carpeting!). Two measuring scales with arbitrary units from 1 to 100 run in opposite directions on the table top between the light sources. The scales run from 1 to 100 for ease in figuring proportions even though the scale is actually 150 cm. long.

The light sources are 15 watt frosted incandescent lamps, the box at one end having four lamps, the other end one. The boxes containing the lamp assemblies are painted black and the bulbs are recessed inside black felt-lined holes for light baffling. The box with four lamps has a slide in front of it with holes allowing the user to expose 1, 2, 3, or 4 lamps to that side of the photometer.

The photometer was made by heating a piece of steel tubing approximately 3" in diameter with half inch walls with a heat lamp. Once hot enough, a small amount of paraffin was placed on the top edge and allowed to melt. A piece of ordinary typing paper was then placed on



top of the paraffin, and a weight placed on top of the paper while the paraffin soaked in forming a doughnut shaped ring. (We had to experiment with the amount of paraffin to use) **Both the steel and the paraffin must be very clean for the best results.** The photometer was then laminated in plastic for durability and mounted in a wooden stand.

The area in which the exhibit is to be located needs to be fairly dark or the photometer will be swamped with light from the room. We have covered all sides of the exhibit except for the front with black light-proof material to limit external illumination. All graphics including the signs and measuring scale have been made with white letters on black background to eliminate stray reflected light.

Critique and Speculation

As mentioned above, the exhibit is very sensitive to any external light in the area and must be in dark surroundings. If your area isn't dark enough, a curtain hanging in front of the exhibit might solve the problem. Some people have trouble using the the slide on the

light bulb housing; detents at each of the appropriate positions would be useful. The slide could even be replaced completely by putting a switch on each lamp to control how many are on. Slight errors in the measurement of the relative intensities are due to the fact that the sources are not points and that the four lamps are not exactly centered on the photometer. Stray light from outside the exhibit also affects measurements.

Additions and Changes (1990)

We recently modified Grease Spot Photometer to create a new exhibit called Light Edge Photometer. In Light Edge Photometer, the card with the grease spot has been replaced with two sheets of translucent 1/4" white plexiglass, placed to make a sort of plexiglass sandwich. A piece of aluminum foil or other opaque material is sandwiched between the two plexiglass sheets. When both sides of the sandwich receive the same amount of light, the two sheets of plexiglass match when you view them from the edge. If one side receives more light, it is noticeably whiter. The Light Edge Photometer has better resolution than the Grease Spot Photometer. This allows teachers to use the exhibit quantitatively, making measurements that give results that are more or less consistent with theoretical expectations.

Although the Light Edge Photometer is more accurate, some of our staff members feel it is much less aesthetically pleasing than the Grease Spot Photometer. We suggest you supply your visitors with both.

Related Exploratorium Exhibits

LIGHT INTENSITY

Horse's Tail - Gray Step 1
Rotating Gray Step - Gray Step 2
Mondrian - Gray Step 3

Exploratorium Exhibit Graphics

To do and notice:

Notice that in the center of the white card is a translucent "doughnut"; this area has been soaked in wax.

If you move the card along the table, the doughnut changes from light to dark. At one point the doughnut blends with the card. In this position the light intensity is the same on both sides of the card.

The box on the left has a slide which allows you to select from one to four lights. Notice that with one light at each end of the table, the doughnut disappears when the card is about halfway between the two lights.

If you place the dark plexiglass in front of the left hand box with four lights exposed, the doughnut also blends with the card when it is about halfway; the dark plastic lets through about one quarter of the light.

Try a variety of combinations of lights, and observe at which position the spot disappears. Do this with or without the dark plexiglass in front of either light box.

Notice that when one light source is four times as bright as the other, the distance from the bright light source to the card is only about twice the distance from the card to the dim source.

More generally, you can compare the brightness of the lights by comparing the squares of the distances from the light sources to the card.

What is going on:

This kind of photometer, or light meter, is often called a "grease spot photometer". One can produce a card such as the one in this exhibit by taking a piece of white writing paper and rubbing a little oil or butter around the center of it. With such a piece of paper you can compare the light intensity of different lights around your house. (In order for the spot to completely disappear the different lights must have the same color and not merely the same intensity.)

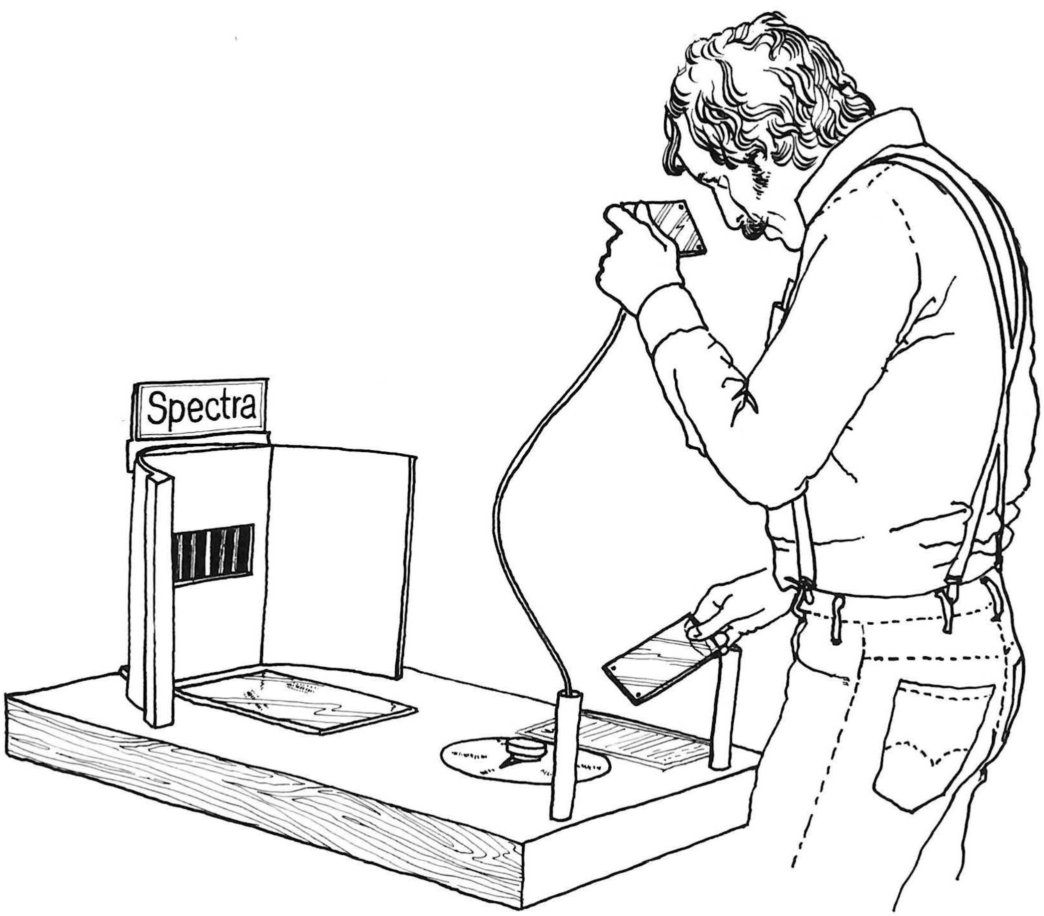
The grease spot photometer is so effective because of the way the eye works. In several other exhibits in the vision section there are effects that have to do with the way light on one part of the retina makes the neighboring part of the retina less sensitive. When light falls on one part of the retina, it inhibits the sensitivity of neighboring parts.

This effect, called lateral inhibition, heightens the contrast between two areas of different brightness. If the center part is slightly brighter than the surrounding part, the center part inhibits the surrounding part of the retina in the eye and makes the surrounding part seem even dimmer than it would be without this form of inhibition.

On the other hand, the dim surrounding part, since it is dim, doesn't inhibit the bright part as much. Therefore the bright part looks a little brighter and the dim part looks a little dimmer. In other words, the contrast is increased. It is because of this lateral inhibition that the grease spot photometer is really a very sensitive instrument.

We have soaked the central spot with paraffin wax rather than grease because the paraffin lasts longer than grease.

Spectra



Description

The emission spectra of various gases may be examined using diffraction grating viewers and compared to other sources of lighting around the museum.

Construction

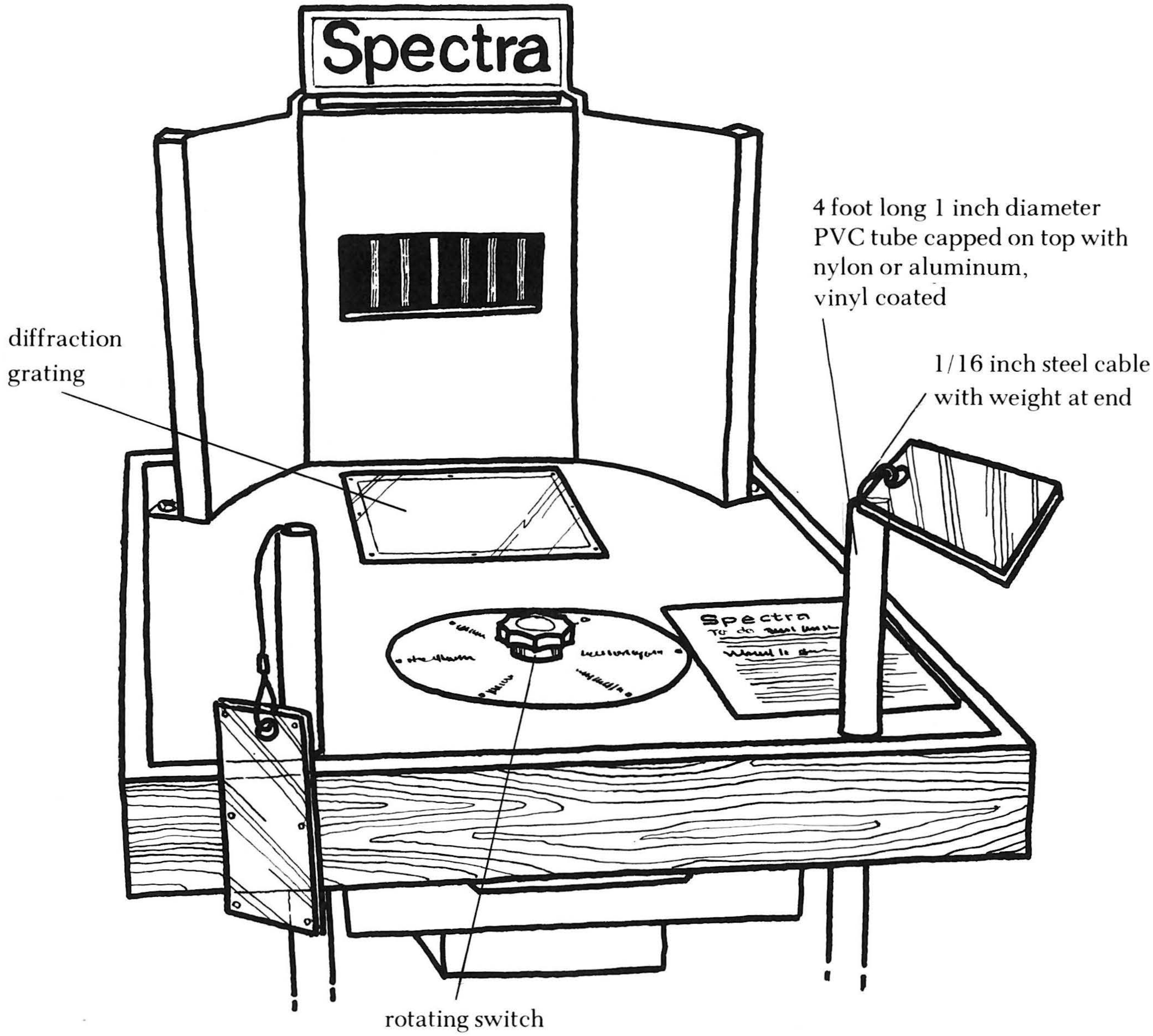
The exhibit is designed around spectrum tubes and power supply available from:

Edmund Scientific
1892 Edscorp Building
Barrington, N.J. 08007
tel: (609) 547-3488

The following tubes were selected for use in our exhibit:

Argon
Mercury Vapor
Neon
Nitrogen (molecular spectrum)
Helium
Xenon

The power supply delivers 5000 volts at 7 mA to power the tubes. The tubes are mounted behind a plexiglas® window in a piece of plywood so that only the thin part of the tube shows. Black felt is placed behind the tubes and is partially



wrapped around them to keep the light from one tube from reflecting off of its neighbor, producing a double spectrum. "Wings" stick out on both sides of the spectrum tube box to provide a black background against which the spectrum can easily be viewed.

Only one tube can be lit at a time by selecting it with a six position rotary switch. This must be a high voltage switch with the contacts mounted on porcelain insulating wafers as the 5000 volts is being switched. To prevent arcing between positions, a microswitch riding on the detent of the rotary switch turns the 120 volts to the transformer off and on. The transformer and high voltage switch are mounted under the table covered by a box with the wires running to the spectrum tubes

inside a thick cardboard tube also affixed to the underside of the table.

The spectrum viewers are simply diffraction gratings sandwiched between two pieces of 1/16" plexiglas® and tied to the table with a weighted steel cable. A piece of reflection grating is affixed to the top of the table (beneath a piece of protective plastic) under the tubes to provide an additional method for viewing the spectrum. The grating material is available from Edmund Scientific.

Critique and Speculation

The diffraction grating available from Edmunds is of rather poor quality and, with the advent of holography, gratings of higher efficiency and dispersion are available or can be made at a reasonable cost. (We use the holographic grating when it is available.) A prism viewer could also be built (Edmunds has some great 60 degree spectroscopy prisms) but would be more delicate and expensive.

Additions and Changes (1990)

When inserting the diffraction gratings into the holders be sure to orient the grating so that the spectrum spreads out to the left and right, not to the top and bottom.

The simplest way to build this exhibit would be to use six different transformers—one for each neon tube. We get our transformers and tubes from:

Electro-Technique
4642 North Ravenswood
Chicago, IL 60640
tel: (312) 561-2349

Spectra-tube Transformers (010-0008-3) cost about $50 each (1990 price). However, if you are trying to keep costs down or if transformers are not available, you may be able to use the distributor from a six-cylinder automobile to both switch the transformer primary off and on as well as switch to the different tubes. We haven't tried this, but we believe it's possible.

The exhibit is switched on and off with a mat switch (or a push button with a timer), so that the exhibit won't be left running when the visitor leaves. This extends the life of the tubes.

We don't use hydrogen tubes because contaminants from the metal parts of the tube cause the spectrum to wash out. The other tubes will also eventually be affected by contaminants, so we check and replace them.

Related Exploratorium Exhibits

Iron Sparks
Hot Light
Sun Painting
Solar Signature

Exploratorium Exhibit Graphics

To do and notice:

Look through the viewer at the gas filled tubes. You will see lines of color off to the side.

What is going on:

Each different gas, excited by an electric current, gives off a unique combination of colors or "spectrum" that is as characteristic of that gas as a fingerprint is to a person. You can identify the gases of distant stars by their spectra.

The viewer is a diffraction grating, a row of microscopic lines. When light passes between the lines it fans out into varied colors.

Stored Light

Description

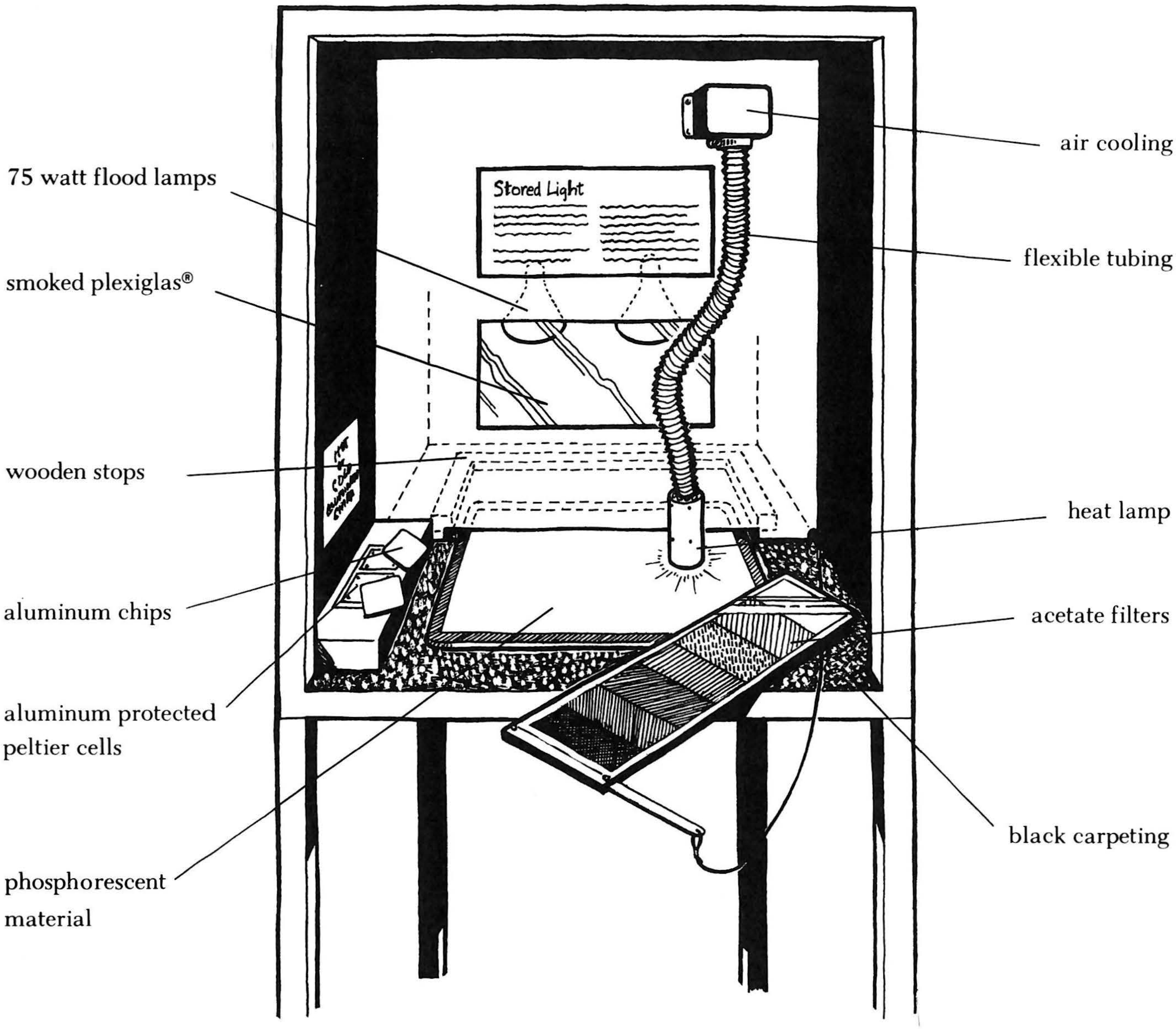
The phenomenon of phosphorescence can be explored with this exhibit as well as the effect of heat and cold on the phosphorescent material. The reaction of the material to various colors of light can be examined with colored filters attached to the exhibit.

Construction

The exhibit is built around a frame of welded 1" square steel tubing with 1/16" walls. The sides, top, and back of the upper portion of the exhibit are covered with 1/4" masonite which is sealed with a coat of lacquer sanding sealer. The box is divided into two halves, front and rear, with all of the electronics, lamps, and fans inaccessible to the public in the rear half behind a locked door.

The phosphorescent material is an adhesive backed vinyl sheet available from:

Canrad-Hanovia, Inc.
100 Chestnut Street
Newark, NJ 07105
tel: (201)589-4300



Order Series 4100 CLL. This material comes in rolls 24" wide and 30 feet long and is 1/32 to 1/16" thick. Our phosphorescent screen is 15x20" and is backed with a layer of 1/8" masonite. It fits through a 1" high slot in the wall separating the front half of the exhibit from the back. The slot is at table level. The top of the table is covered with black carpet (apparently available only from auto upholstery vendors) to reduce reflections. The phosphorescent material is "charged" on the other side of the divider by two 75 watt flood lamps which can be viewed through a window in the divider made of 3 layers of 1/4" smoked plexiglas®. The graphics are mounted in the divider and are dimly rear lit by small incandescent lamps.

A heat lamp hangs from the exhibit for use in heating the phosphorescent material by radiation. An FDV quartz

halogen lamp is housed in an aluminum tube with a red (and infrared) passing dichroic filter at the end of the tube. The delicate filter is protected by a piece of 1/16" glass over it. The heat lamp is forced air cooled through a piece of flexible tubing (our tubing is a surplus pressure demand oxygen mask hose from an aviators helmet). The wires from the lamp and a supporting steel cable run inside the hose to the exhibit.

Aluminum chips 1-1/2" square and 1/8" thick are heated or cooled by laying them on top of peltier cells. These cells (available from Cambion) are mounted on a forced air cooled heatsink and are protected by a piece of aluminum over them. Two peltier cells, mounted side by side, are used for cooling and heating. Since the cool cells condense water from the air, a drain must be provided to remove the excess water. Because aluminum chips get lost or pushed into the back of the exhibit, a small storage bin for extras has been provided.

The various colored acetate filters are sandwiched between 1/8" plexiglas® and cabled to the exhibit. The filters (red through blue) were selected for the best "grey scale" on the exposed phosphorescent material though the filters have widely varying color and density.

The exhibit must be placed in a dark area and shielded from as much external illumination as possible since the phosphorescent material does not glow very brightly.

Related Exploratorium Exhibits

PHOSPHORESCENCE

Glow Wheel
Line by Line
Shadow Box

Exploratorium Exhibit Graphics

(an exhibit about phosphorescence)

The material used in this exhibit is the same as the material on the walls of the Shadow Box.

To do and notice:

● Slide the green material through the slot beneath the white lights. Pull it back out and notice that it is glowing.

● Place the colored filters on top of the green material. Slide them together under the light and back out again. Notice that the material glows beneath the blue filter and some of the green filters, but not beneath the yellow or red filters.

● Expose the material to the light and place the red 'lamp' on top of the material for five seconds. Notice that there is no longer any glow in the circular area beneath the lamp.

● Expose the material to the light again and after you remove it, quickly place the hot and cold aluminum chips on top of the material for about ten seconds, and then remove them. Notice that the area beneath the hot chip is glowing more than the surrounding area. The area beneath the cold chip is glowing less. As you watch them, the dark square becomes brighter, and the bright square darker.

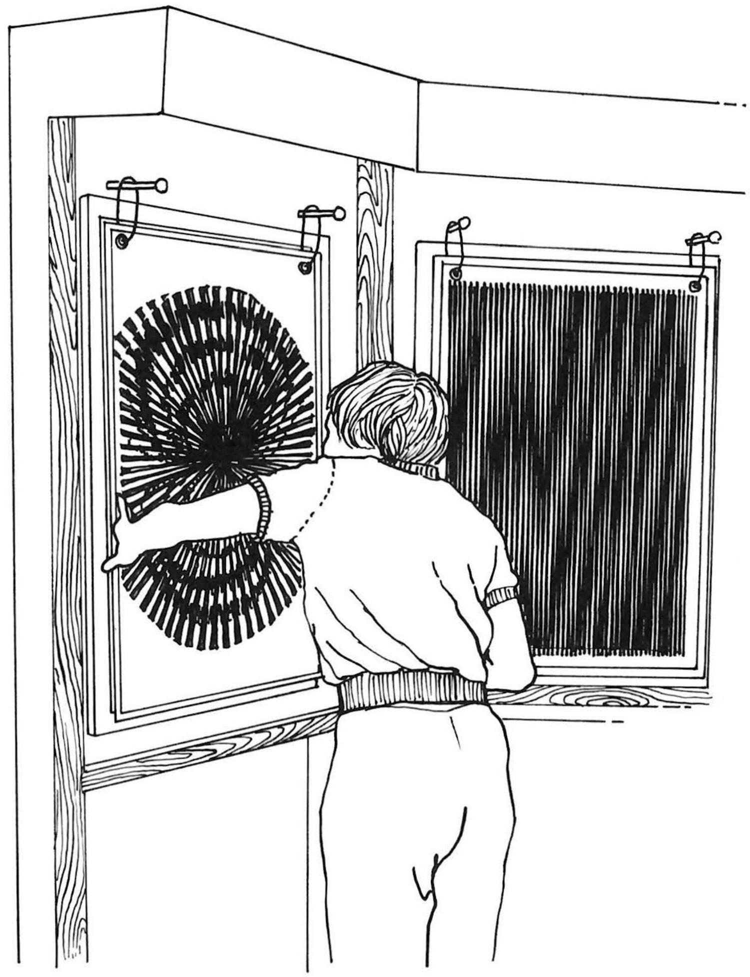
What is going on :

All materials absorb light radiation. After absorbing the light, the material may do any one of a number of things. It may immediately emit the light as reflected light, it may convert the light energy to heat or use it to initiate some chemical reaction, or it may store the energy for a while before emitting it as light.

Phosphorescent materials demonstrate just one of the many ways in which matter interacts with light. The material in the exhibit absorbs only blue visible light and emits only green visible light. When the color filters are placed over the material, only the material beneath the blue filters begins to glow. There is either a green glow or else no glow at all.

Blue light is absorbed instantly by this material, but the green light leaks out slowly. The material can absorb the energy of the blue light and still remain relatively stable - that is, the light energy comes out slowly. If heat is added to the material, it becomes less stable and emits the green faster. The addition of infrared radiation makes it even more unstable, and it emits all the energy in just a few seconds. Cooling the material makes it more stable than it is at room temperature, and it stores the energy until it warms up, at which time it begins to glow again.

Moiré Patterns



Description

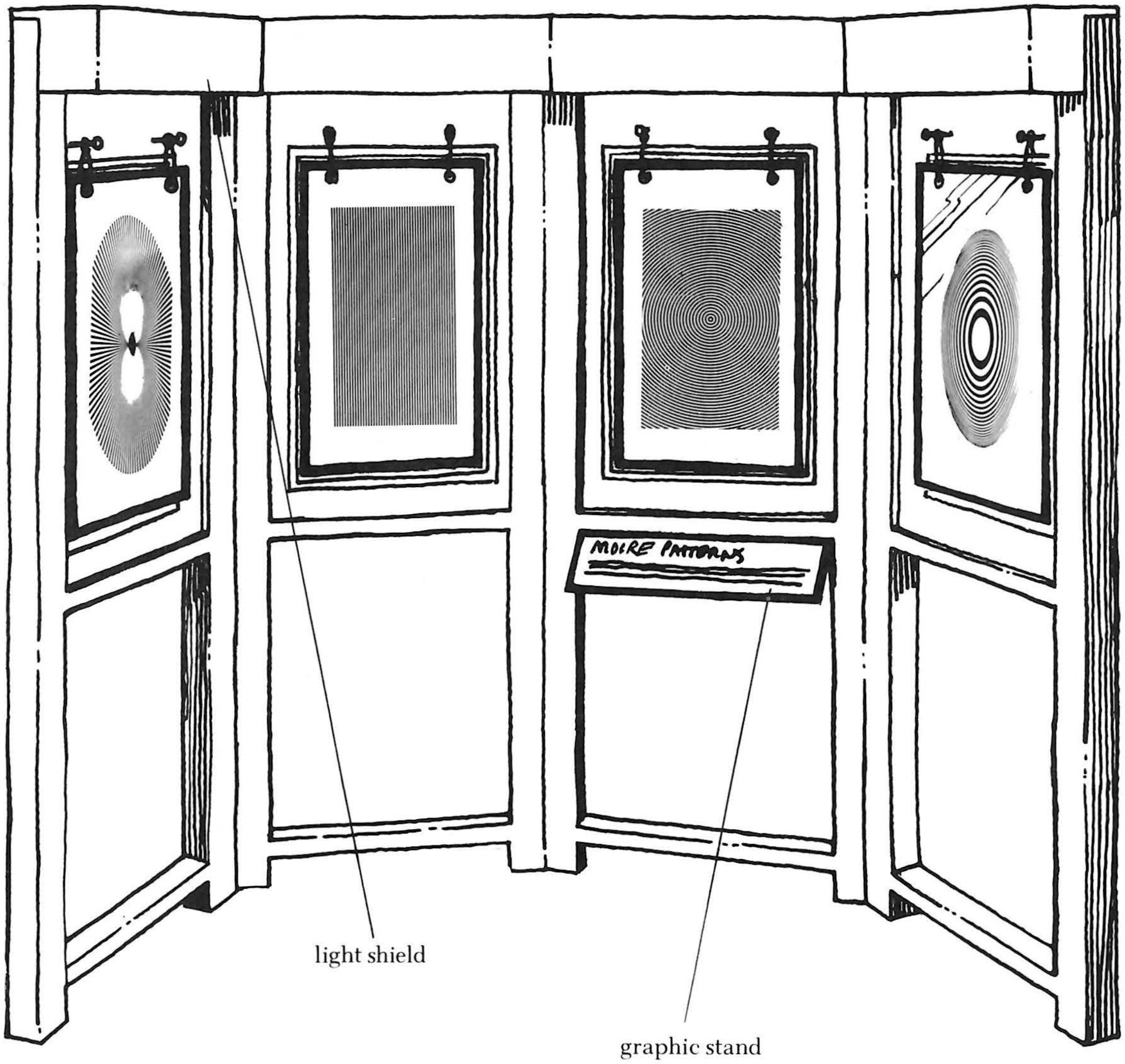
Four different types of moiré patterns are displayed in this exhibit. The moiré patterns are created with a transparency of a regular geometric pattern overlaying an exact copy of itself. The "interference" between the lines in the transparency and the lines in the print underneath form the moiré pattern.

Construction

This exhibit is constructed on a partial (4 sided) octagonal backboard structure made of varnished plywood and 3x3 (cut from 4x4) lumber. This structure is free standing and is quite stable. The moiré patterns are mounted to the four internal surfaces of the partial octagon (although things could be mounted on the outside as well). One could mount the moiré patterns on a wall with equally satisfactory results.

We use 4 different patterns:

1) Radiating lines
2) Parallel lines
3) Concentric equidistant circles
4) Concentric converging circles

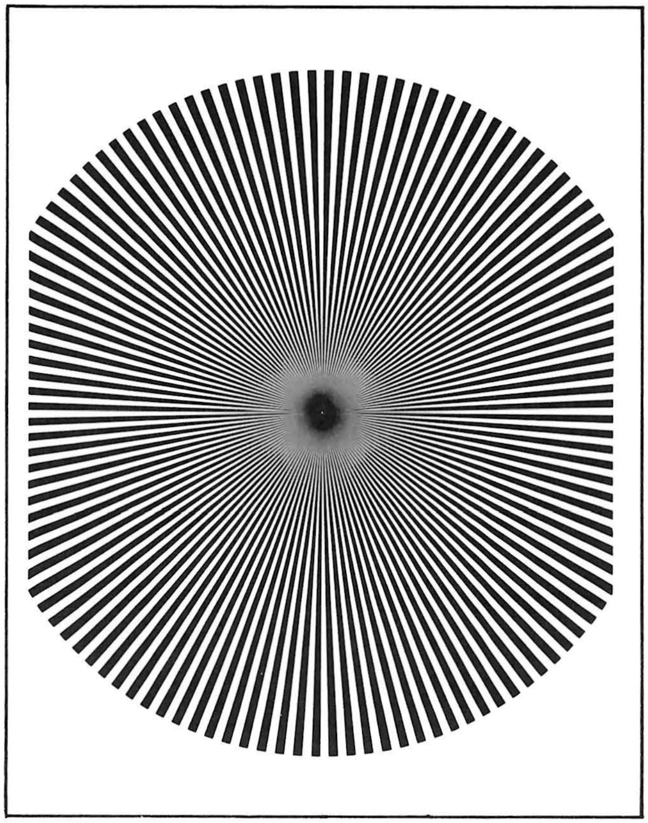


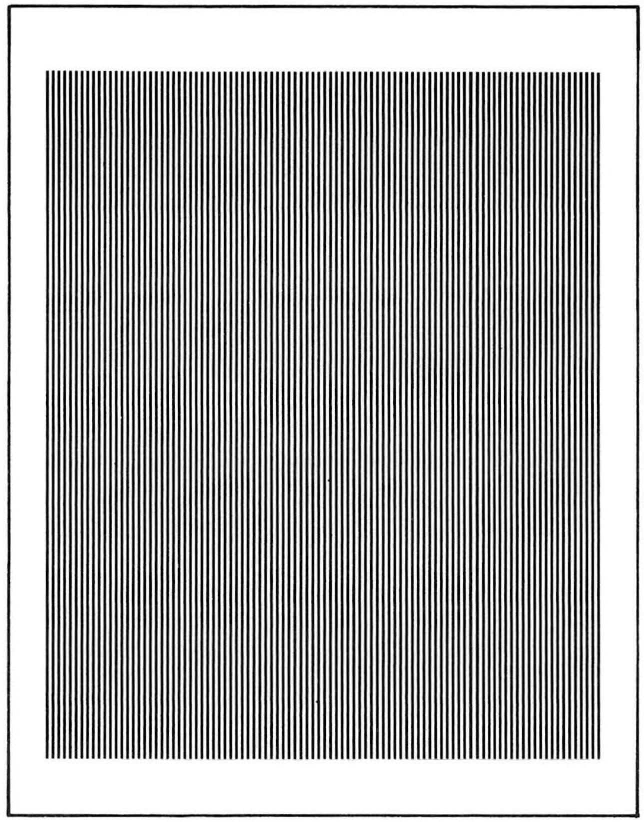
Our pattern prints and transparencies were originally photographed from the Edmund Scientific Moiré pattern kits, blown up to 8x10 inch negatives and then to the final 20x24 inch size found in the exhibit. It is very important that the print and the transparency be exactly the same size so that when they are perfectly overlapped they do not "interfere".

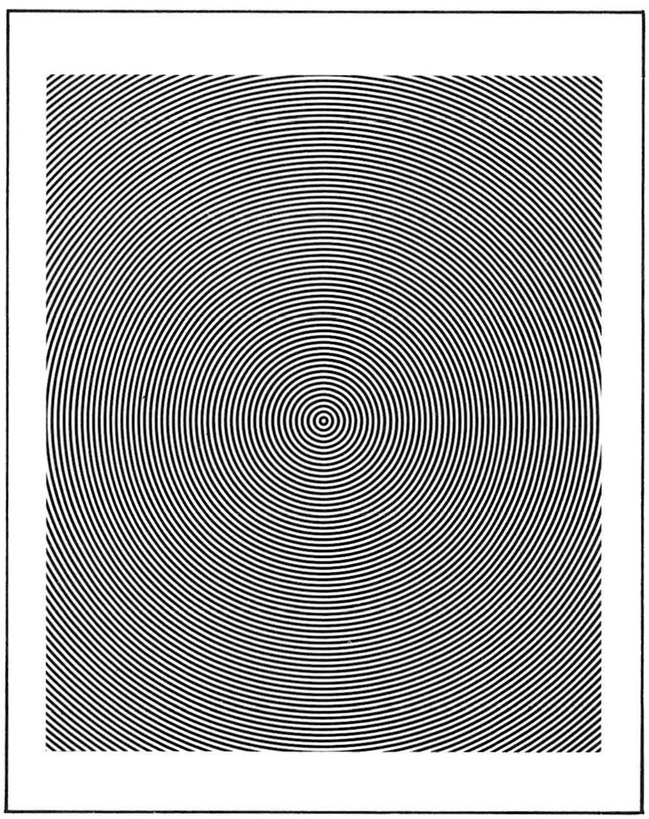
The prints are mounted to the backboard with a thin wooden frame surrounding them to keep the edges from becoming frayed. The transparencies are sandwiched between layers of 21.5x28.5 plexiglas® 1/8 inch thick. The edges of this sandwich are protected by edging of the type used on report cover spines. Two grommets are placed in the upper corners to allow hanging.

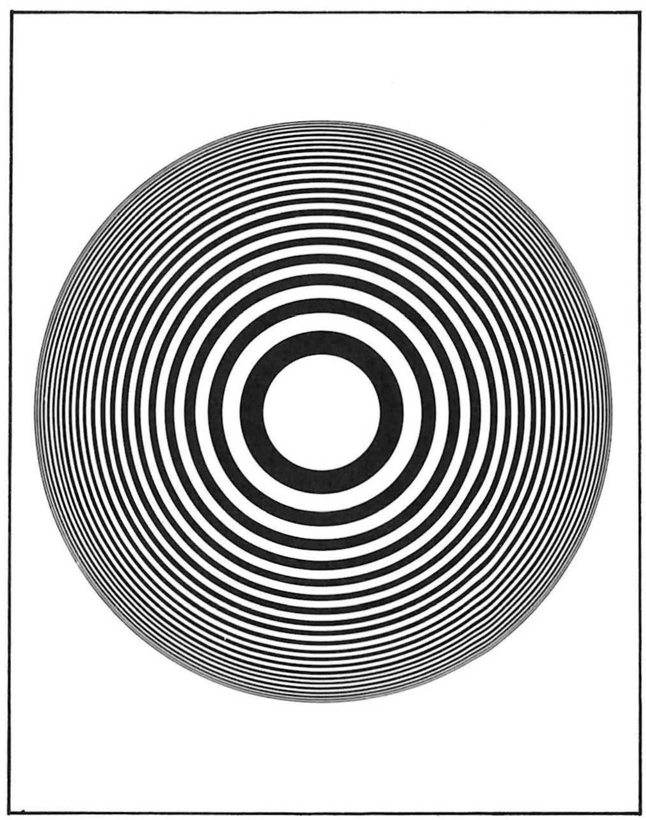
The transparencies are hung from a large 1/2 inch carriage bolt. A steel ring, too small to fit over the head of the bolt is made and the transparency is hung from this ring with small (2" diameter) steel cable loops. The carriage bolts stick out about 4" from the backboard. This allows the viewer to step back and see the moiré patterns due to the parallax between the front and back patterns.

Each pattern is illuminated by a









fluorescent fixture containing two 20 watt bulbs which are shielded by a wooden light trap. This light trap keeps the direct light from the lamps out of the viewer's eyes. It also keeps the light from spilling onto other exhibits and "light polluting" the general area (our area is darkened for other exhibits).

Critique and Speculation

We have only tried a few of the many possible patterns which would work in this exhibit. Some of the patterns were chosen because they illustrate various physical phenomena in the museum, the interference of two circular or plane waves for instance, thus providing links between the various sections in the museum.

Additions and Changes (1990)

This exhibit should be constructed so that it can be broken down into two halves easily. Otherwise, the exhibit is very difficult to move.

Related Exploratorium Exhibits

BEATS, SPATIAL

- **Picket Fence Beats**
- **Walking Beats**

MOIRES

- **Harmonograph-Drawing Board**
- **Fluorescent Rods**

INTERFERENCE

- **Water Waves**
- **Bridge Light**

Exploratorium Exhibit Graphics

To do and notice:

Notice that when you push the outer frame against the wall, the patterns match perfectly.

When the front pattern hangs away from the wall, notice that the overlapping of the patterns makes an apparent superimposed pattern called a moire pattern.

The scale of the moire pattern changes when you back away from the moire patterns or when you change the distance between the two patterns.

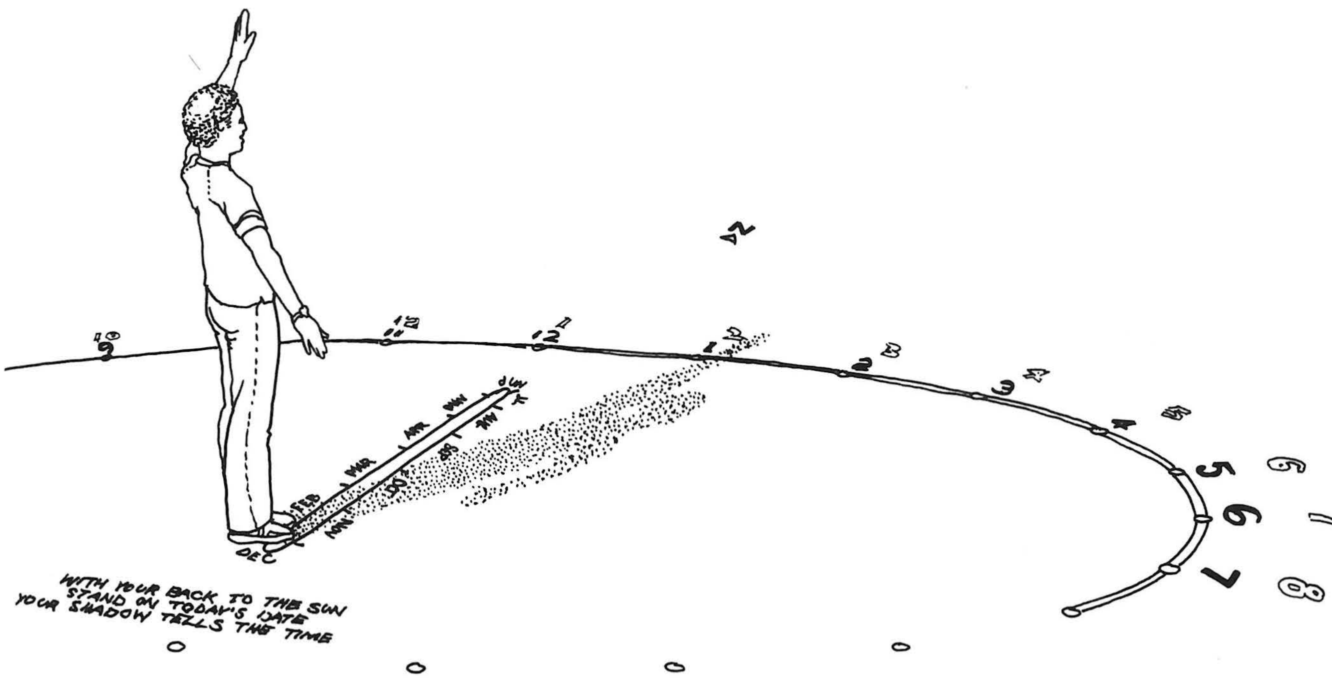
Because the front pattern is closer to you than the rear pattern, the front pattern makes a bigger image in your eye than the back pattern.

Therefore, the black lines of the two patterns get out of step with each other, and the black lines of the front pattern overlap the white lines of the back pattern.

It is this repetitive overlapping which gives rise to the moire pattern.

Recipe No. 134

Sun Dial



Description

A person stands on a date marker for that date and her shadow is cast toward the time marked on a large ellipse.

Construction

This sundial, called an "analematic" dial, is very simple to lay out in a parking lot or southerly facing patio of a building. After doing the calculations which follow, it will only take one pleasant afternoon to chalk out and another to paint.

The first step in the process is to find true north. There are three basic methods, the first and last of which we have tried:

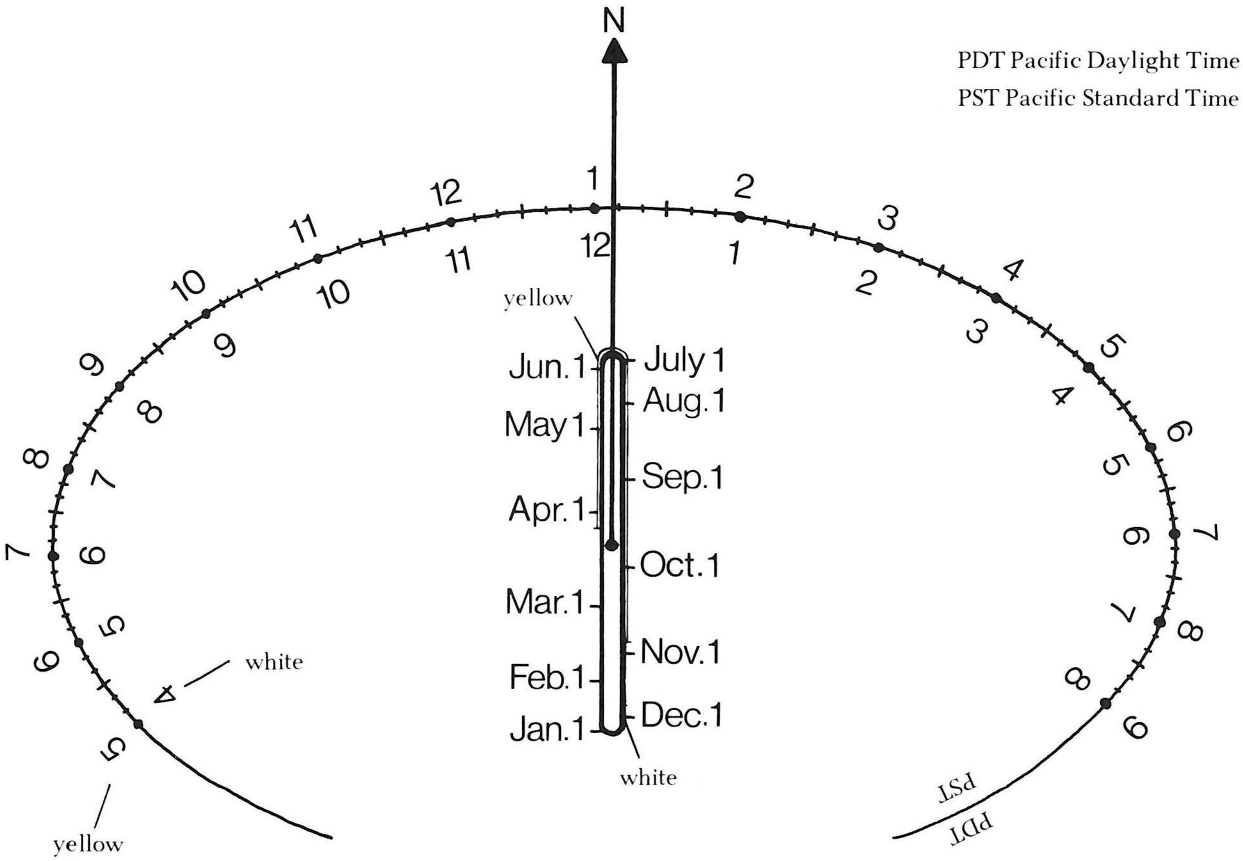
1) Determination by compass

2) Determination by sighting on Polaris

3) Determination by the shadow of a vertical object at true local noon

If true north is to be found with a compass, then the effect of magnetic variation must be accounted for. Magnetic variation is the difference between true north and magnetic north. This information can be obtained from a local geologic or topographic map (It amounts to 17 deg. in San Francisco!). Taking a sighting on the North Star (Polaris) will give you true north accurate to 1 deg.

The third method requires that the time of **local apparent noon,** ie. when the sun is directly south, be calcu-



Place vertical gnomon on today's date.
The shadow points to the time.

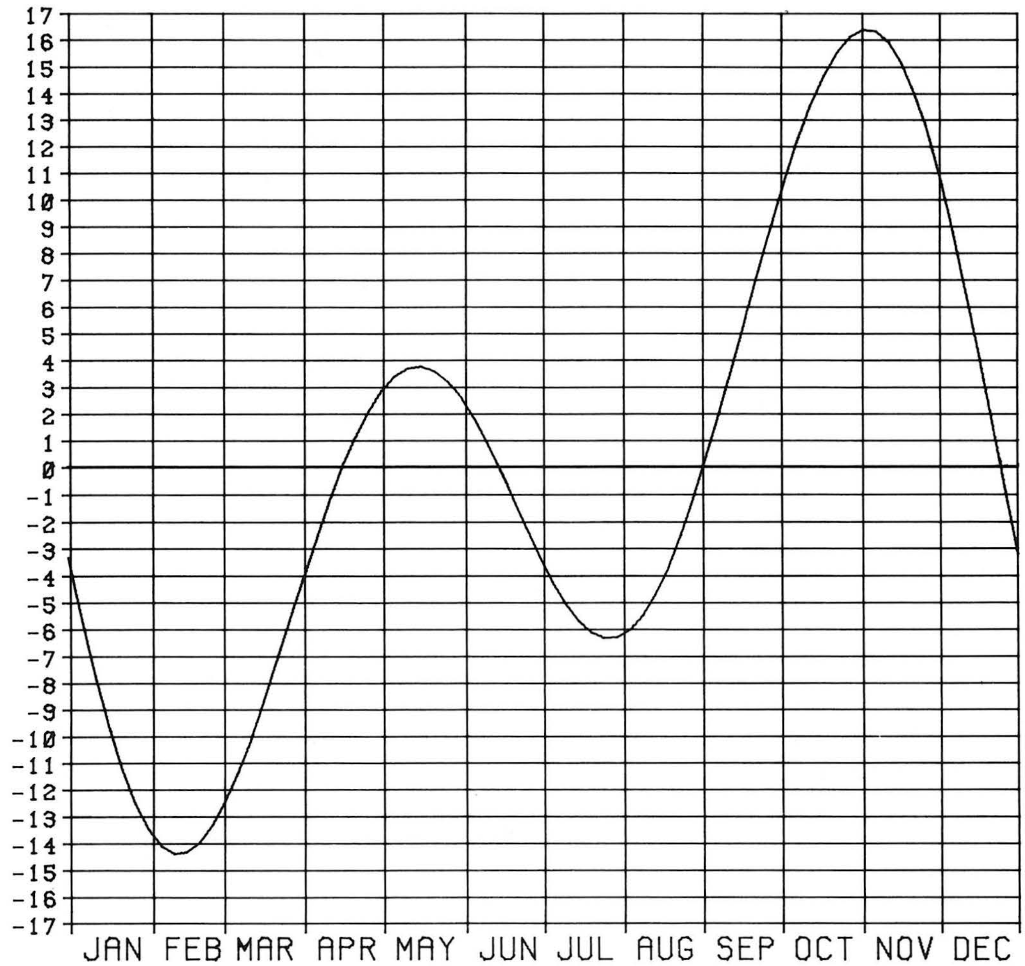
lated. At this calculated time, a shadow cast by any vertical object such as a plumb line will be lined up due north-south and can be marked on the ground for further work. To determine the time of local apparent noon, two things must be taken into account - the Equation of Time (ET), and the longitude of the dial. The ET is the difference between the time read on a sundial (**LOCAL APPARENT TIME**) and the time read from an evenly running clock(**LOCAL MEAN TIME**). The difference, which can amount to as much as 16 minutes, is due to the tilt of the earth's axis (23.5 deg) and the changing velocity in our elliptical orbit around the sun. The ET therefore depends on the date and can be found from the accompanying graph.

The longitude correction depends on the difference in longitude between the standard time meridian and the sundial. Since the earth rotates once (360^o)in 24 hours, from west to east, for each degree to the east of the standard meridian, you subtract 4 minutes, and for every degree to the west, you add 4 minutes. For example, in San Francisco at longitude 122.5 deg. west, our standard time meridian for Pacific time is 120 deg.. Our correction would then be (122.5-120)x4 min. = 10 min.. The time of local noon using the factors is:

time of noon=12:00 +/- long. corr. - ET

Remember, the longitude correction is - if the dial is to the east of the

Equation of Time Correction Factor



standard time meridian and + if west. Standard time meridians for the U.S. are:

120 deg - Pacific
105 deg - Mountain
90 deg - Central
75 deg - Eastern

EXAMPLE: In San Francisco, local apparent noon on May 1st occurs at

12:00+10 min+(-2.9 min)=12:07:06 P.M.

At this time a plumb bob string will cast its shadow directly north-south.

Now that we (finally) have a line on the ground running north-south, lay out a grid with a chalk line with one foot (or meters if desired) squares and mark a center for your coordinate system (0,0) which will be the center of the dial. The major axis of the ellipse will be on the "x" (east-west) axis, and the minor axis on the "y" (north-south) axis. If the major axis is "M" feet (meters) long (we recommend M = 15 to 20 feet), the minor axis m = Msin(lat) where "lat" is your latitude.

The x and y coordinates of the hour marks on the ellipse are found with the following formulae:

X = M sin(T +/- long. corr.)
Y = M sin(lat) cos(T +/- long. corr.)

In these equations M is the length of the major axis, the longitude correction is in **degrees** (not minutes as above) and is - if east and + if west.

Declinations of the Sun

for the first day of each month.

Jan.	-23°04′
Feb.	-17°20′
Mar.	-7°49′
Apr.	+4°18′
May	+14°54′
June	+21°58′
July	+23°09′
Aug.	+18°10′
Sept.	+8°30′
Oct.	-2°57′
Nov.	-14°14′
Dec.	-21°43′

"T" is the hour angle of the sun from noon for the desired times, ie. noon = 0 deg, 1PM = 15 deg, 2PM = 30 deg, 11AM = -15 deg, 10 AM = -30 deg, etc.. We recommend that T range from -120 deg to 120 deg (4AM to 8PM).

Once the x-y coordinates of the hour marks (and you may want to add half hour marks too) have been determined, they may be laid out on the previously marked grid with chalk. Sketch in the ellipse between the points. Note that each hour mark will represent one time during daylight savings time and one hour later during standard time. A discussion about labeling will be found further on.

The place that the person stands varies during the year because the declination (celestial latitude) of the sun varies in a yearly cycle (23.5 deg north and 23.5 deg south of the celestial equator due to the tilt of the earth's axis). The distance north or south of the center of the dial at which the person stands can be found using the following formula:

$$Z = M\tan(dec)\cos(lat)$$

where "dec" is the declination of the sun for that particular date. We mark only the beginning of each month and the person interpolates for the correct date. The declination of the sun for these dates can be found in the accompanying table. Once these points have been marked on the y-axis (minor axis) the lay out is finished and you may proceed to try and tell the time (if it's sunny).

To make the dial permanent, we have painted it onto the asphalt surface of our parking lot with highway paint. Highway paint has a very quick drying time and may be applied with a brush if done quickly. On cement, the surface will have to be prepared for painting or the paint might peel. Consult your local paint store for recommendations.

Our color scheme was designed to make the reading of the time as easy as possible. Two sets of hour numbers are painted around the ellipse, one white for standard time and the other yellow for daylight savings time. One set is inside the ellipse and the other outside, above or below their respective hour marks. The ellipse is painted red. The place where people stand is marked by a very skinny oval with tick marks denoting the beginning of each month. The oval and month labels are painted in the proper color (white or yellow) depending on whether that date is standard or daylight savings. Daylight savings starts about April 29 and ends about October 29. The instructions, painted in front of the dial read "Stand on today's date, your shadow tells the time". Compass marks and letters (N, E, S, W) are painted outside the dial to give some idea of direction.

Critique and Speculation

Since people walk on (and cars drive over) these sundials, they need to be repainted at least once a year. This type of sundial does not take into account the equation of time and can therefore be off by as much as 16 minutes. If a placard with the equation of time and an explanation of it were handy to the user, the sundial would be more effective.

For those with access to a computer or microcomputer which speaks BASIC, a program has been included which will give the x and y coordinates of the time marks and the Z coordinates for the center of the dial. This program was written in Northstar BASIC and should run on most computers with little or no modification.

An excellent reference on sundials is:

Sundials - Their Theory and Construction
Albert E. Waugh
Dover 0-486-22947-5

(Available at the Exploratorium Store)

Related Exploratorium Exhibits

Sun Painting

Exploratorium Exhibit Graphics

WITH YOUR BACK TO THE SUN
STAND ON TODAY'S DATE
YOUR SHADOW TELLS THE TIME

Computer Program

```
100 REM - ANALEMATIC SUN DIAL COORDINATES
110 REM - COPYRIGHT 1980  R. HIPSCHMAN
120 DIM M$(10),U$(10)
130 Z$=CHR$(27)+"v"\REM - CLEAR SCREEN CHARACTERS
140 INPUT "LATITUDE - ",L1
150 INPUT "LONGITUDE - ",L0
160 INPUT "MAJOR AXIS - ",M0
170 INPUT "FEET OR METERS? ",U$
180 INPUT "OUTPUT DEVICE # - ",O
190 PRINT Z$
200 M0=.5*M0\REM - SEMIMAJOR AXIS
210 M1=M0*SIN(L1*3.14159265/180)\REM - SEMIMINOR AXIS
220 REM - FIGURE COORDINATES FOR HOURS AND HALF HOURS
230 C=L0-(INT(L0/15)*15)\REM - LONGITUDE CORRECTION
240 PRINT #O,"ANALEMATIC SUNDIAL COORDINATES FOR LATITUDE",L1," LONGITUDE",L0
250 PRINT #O,"                      MAJOR AXIS",2*M0,
260 IF U$(1,1)="M" THEN PRINT #O," METERS" ELSE PRINT #O," FEET"
270 PRINT #O\PRINT #O
280 PRINT #O,"  TIME                 X COORD                Y COORD"
290 PRINT #O,"------------------------------------------------------------------"
300 FOR T=-120-C TO 120-C STEP 7.5
310 T1=12-(ABS((T+C)/15))
320 IF T+C>0 THEN T1=(T+C)/15\REM - P.M.
330 IF T+C=7.5 THEN T1=12.5
340 IF T+C=0 THEN T1=12
350 PRINT #O%3I,INT(T1),":",\REM - FORMATTED PRINTING OF TIME
```

```
360 IF INT(T1)=T1 THEN PRINT #O,"00  --    ", ELSE PRINT #O,"30  --    ",
370 X=M0*SIN(T*3.14159265/180)\REM - "X" COORDINATE
380 Y=M1*COS(T*3.14159265/180)\REM - "Y" COORDINATE
390 IF U$(1,1)="M" THEN X=FNA(X)\REM - PRINT X IN METERS
400 IF U$(1,1)="F" THEN X=FNB(X)\REM - PRINT X IN FEET/INCHES
410 PRINT #O,"      ",
420 IF U$(1,1)="M" THEN Y=FNA(Y)\REM - PRINT Y IN METERS
430 IF U$(1,1)="F" THEN Y=FNB(Y)\REM - PRINT Y IN FEET/INCHES
440 PRINT #O
450 NEXT T
460 PRINT #O\PRINT #O\PRINT #O
470 PRINT #O,"DATE               Z"
480 PRINT #O,"--------------------------------"
490 FOR I=1 TO 12
500 READ D,M$
510 D=D*3.14159265/180\REM - CONVERT TO RADIANS
520 Z=M0*(SIN(D)/COS(D))*COS(L1*3.14159265/180)
530 PRINT #O,M$," ----- ",
540 IF U$(1,1)="M" THEN Z=FNA(Z)\REM - PRINT Z IN METERS
550 IF U$(1,1)="F" THEN Z=FNB(Z)\REM - PRINT Z IN FEET/INCHES
560 PRINT #O
570 NEXT I
580 PRINT #O\PRINT #O,"MAXIMUM EXCURSION = +/-",
590 D=23.4367*3.14159265/180\REM - CONVERT OBLIQUITY TO RADIANS
600 Z=M0*(SIN(D)/COS(D))*COS(L1*3.14159265/180)
610 IF U$(1,1)="M" THEN Z=FNA(Z)\REM - PRINT Z IN METERS
620 IF U$(1,1)="F" THEN Z=FNB(Z)\REM - PRINT Z IN FEET/INCHES
630 PRINT #O
640 REM - DATA FOR DECLINATION OF SUN ON 1ST DAY OF THE MONTH
650 DATA -23.133333,"JAN",-17.3,"FEB",-8,"MAR",4.25,"APR",15,"MAY"
660 DATA 22,"JUN",23,"JUL",18,"AUG",8.5,"SEP",-2.9,"OCT",-14,"NOV"
670 DATA -21.66667,"DEC"
680 END
690 DEF FNA(I)\REM - PRINT COORDINATES IN METERS
700 PRINT #O,"   ",%5F2,I," METERS",
710 RETURN I
720 FNEND
730 DEF FNB(I)\REM - PRINT COORDINATES IN FEET AND INCHES
740 IF I<0 THEN 770
750 PRINT #O%3I,INT(I)," FT  ",%5F1,12*(I-INT(I))," IN",
760 RETURN I
770 PRINT #O%3I,INT(I+1)," FT  ",%5F1,12*(I-INT(I+1))," IN",
780 RETURN I
790 FNEND
```

Table of Contents for Cookbooks I, II, III

Cookbook No.-Recipe No.

"...a delight to read...I highly recommend the *Exploratorium Cookbooks*."

—Gerald Wheeler in *Physics Teacher*

"*Exploratorium Cookbooks*—the most used do-it-yourself manuals in the science center world."

—Bonnie Van Dorn, Executive Director
Association of Science-Technology Centers (ASTC)

"...whip up some of these dishes, the very same exhibits that crowd the big floor of the Exploratorium....These recipes work, and the pleasure and nutrition of the results repays the cooks."

—Philip Morrison, MIT Physicist
and Phylis Morrison, noted educator,
authors of the PBS series, *The Ring of Truth*

"OK—so there's no such thing as a free lunch. But the *Exploratorium Cookbooks* are amazingly free with original ideas and designs for experiments—used all over the world."

—Richard L. Gregory
Founder of the Bristol Exploratory

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